DEMONSTRATION REPORT

Evaluation of Discrimination Technologies and Classification Results
Live Site Demonstration: Former Waikoloa Maneuver Area

ESTCP Project MR-201104

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14. ABSTRACT

The project involved the processing and analysis of dynamic EM61-MKII data and a cued survey of 1,032 dynamic EM61 data targets with the MetalMapper at the former Waikoloa Maneuver Area. The Cued MetalMapper data were analyzed and the dig list submitted was scored against the ground truth from the intrusive investigation and the blind seeds present in the survey area. Nine seed items placed within the demonstration areas were incorrectly classified as either clutter or soil response on BTG's final dig list. It was concluded that the effects of the background response due to site geology were too significant to allow the correct classification of these targets regardless of processing method. Therefore, the project failed the performance objective of correctly identifying all TOI at the site. Because it was concluded that all targets at the site needed to be excavated to ensure the recovery of all of the TOI, the project failed the performance objective of reducing clutter digs by more than 75%. It was recommended that all anomalies identified in the EM61 detection survey be investigated to ensure that all TOI were recovered.

15. SUBJECT TERMS
MetalMapper, UX-Analyze, UXO, Former Waikoloa Maneuver Area, discrimination, classification

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Final Report

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Acronyms

β1, β2, β3	polarizabilities along principal axes of target
σ	standard deviation
AOI	area of interest
BTG	Black Tusk Geophysics
BUD	Berkeley UXO Discriminator
cm	centimeter
DAQ	data acquisition computer
EM61	EM61-MK2 time domain metal detector
EMI	electromagnetic induction
Environet	Environet, Inc.
ESTCP	Environmental Security Technology Certification Program
ftp	file transfer protocol
FUDS	formerly used defense site
GPS	Global Positioning System
Hz	hertz
ID	identification
in.	inch
ISO	industry standard object
IVS	instrument verification strip
m	meter
MD	munitions debris
MEC	munitions and explosives of concern
mm	millimeter
N	repeat factor
NAD83	North American Datum of 1983
OD	other debris
P_{class}	probability of correct classification
QC	quality control
T	period
TO	task order
TOI	targets of interest
USACE	U.S. Army Corps of Engineers
UTM	Universal Transverse Mercator
UXO	unexploded ordnance
WGS	World Geodetic System
WMA	Waikoloa Maneuver Area

EXECUTIVE SUMMARY

This report describes in detail the procedures, methods, and resources Parsons used to complete an Environmental Security Technology Certification Program (ESTCP)-funded demonstration study at the former Waikoloa Maneuver Area (WMA) in Waikoloa, Hawaii, under ESTCP Munitions Response Project 201104. The 2013 demonstration study at the former WMA was conducted with two primary objectives:

- Test and validate detection and discrimination capabilities of a currently available advanced electromagnetic induction sensor developed specifically for discrimination on real sites under operational conditions.
- Investigate in cooperation with regulators and program managers how classification technologies can be implemented in munitions and explosives of concern (MEC) cleanup operations.

Parsons was responsible for all of the field work conducted on the project, which included EM61-MK2 (EM61) transect surveys of prospective MetalMapper data collection locations, the placement of 97 seed items for use in measuring the capabilities of the MetalMapper at the site, the collection of dynamic EM61 data and selection of targets in the data, the cued survey of 1,032 dynamic targets with the MetalMapper, and the intrusive investigation of the target sources following data collection. While the EM61 transect surveys were conducted as planned, MetalMapper data collection locations were based almost solely on accessibility to the MetalMapper. The former WMA is primarily composed of jagged volcanic rock, and most of it could not be safely traversed by the extendable reach forklift used to transport the sensor. Three separate locations totaling approximately 5 acres of usable land were identified for survey within the site. Even within these relatively flat and even areas, the rocky surface was deemed unsuitable for the collection of dynamic MetalMapper data as originally planned, so the dynamic data were collected using the EM61. Cued MetalMapper data were collected as specified in the Demonstration Plan.

The EM61 and MetalMapper data collection effort took place over 6 weeks and was completed by two field teams. One team began the dynamic EM61 data collection and performed all of the cued MetalMapper data collection; the second mobilized during the project and completed the dynamic data collection while the first began the MetalMapper work. Production rates were extremely slow for both dynamic and cued data collection. Dynamic data collection was slowed by the site terrain and the narrow line spacing required to identify and accurately position smaller ordnance types like 37-millimeter projectiles. The cued data collection was slowed by the terrain and the site geology, which made identifying subsurface targets difficult when they were present and resulted in lengthy searches for dynamic targets that were selected based on geologic response rather than subsurface metal.

The cued MetalMapper data were analyzed by Black Tusk Geophysics (BTG), which provided an initial dig list for the site. The dig list was not fully classified but did include BTG's initial impressions on whether each target appeared to be caused by an actual metallic source or appeared to be an inversion of background. The intrusive investigation was performed following the submittal of this dig list. Targets classified as metallic sources by BTG were investigated using typical ESTCP intrusive investigation protocols. Those classified as likely background

were checked with a Minelab metal detector before intrusive investigation. If the Minelab also indicated that there was no metallic source present, no intrusive investigation was performed.

The dig list submitted by BTG was scored against the ground truth from the intrusive investigation and the blind seeds present in the survey area. Nine seed items were incorrectly classified as nonhazardous clutter on BTG's dig list. Failure analysis indicated that the incorrect classification on one of the nine targets was due to significant offset between the MetalMapper data collection point and the actual location of the seed. The other eight incorrect classifications appeared to be a result of the variable background response produced by the iron-rich volcanic rock at the site. Two were identified as metal that did not match any library objects particularly well and were classified as clutter; the remaining six appeared to be purely derived from soil response and were classified as background. The initial approach taken by BTG in analyzing the data included various methods of removing background, so there are no obvious methods for reprocessing the data to resolve just the response due to the seed items for these targets. BTG's conclusion was that the extreme variations in background across the site affected the data to the degree that these effects could not be overcome. It was recommended that all anomalies identified in the EM61 detection survey be investigated to ensure that all TOI were recovered.

1.0 INTRODUCTION

Currently, up to 90% of excavation costs on most unexploded ordnance (UXO) / munitions and explosives of concern (MEC) projects are related to removing scrap metal that does not represent an explosive hazard. Significant cost savings could be achieved through the use of geophysical discrimination methods that could reduce the number of excavations required to remove explosive hazards from sites. The objective of this project is to demonstrate the use of advanced electromagnetic induction (EMI) sensors in dynamic and static data acquisition modes and associated analysis software. To achieve these objectives, a controlled test was conducted at the former Waikoloa Maneuver Area (WMA) in Waikoloa, Hawaii.

This project was performed as a demonstration study funded by the Environmental Security Technology Certification Program (ESTCP) under Munitions Response Project 201104. This demonstration was designed to evaluate classification methods at a site that is known to contain various munitions, including evidence of ordnance as small as 37-millimeter (mm) projectiles, presents extremely variable terrain and geology, and provides an opportunity to involve a stakeholder community that includes state regulators in the classification demonstration program.

1.1 BACKGROUND

The Fiscal Year 2006 defense appropriation contained funding for the “Development of Advanced, Sophisticated Discrimination Technologies for UXO Cleanup.” The ESTCP responded by conducting a UXO discrimination study at the former Camp Sibert, Alabama. The results of this first demonstration were very encouraging. The conditions for discrimination were favorable at this site and included a single target of interest (TOI), the 4.2-inch (in.) mortar, and benign topography and geology. All of the classification approaches demonstrated were able to correctly identify a sizable fraction of the anomalies as arising from nonhazardous items that could be safely left in the ground. Both commercial and advanced sensors produced very good results. ESTCP organized demonstrations at munitions response sites across the country between 2006 and 2013, generally with new variables added to the classification challenges at each subsequent site (i.e., increased target density, increased response from local geology, mixed munition sizes ranging from small to very large, wooded areas). In addition, the subsequent projects included the use of smaller, man-portable EMI sensors such as the Naval Research Laboratory’s TEMTADS 2x2 cart, Lawrence Berkeley National Laboratory’s man-portable Berkeley UXO discriminator (BUD), and Sky Research’s man-portable vector machine. All of the EMI sensors tested to date have been quite successful in discriminating between TOI and clutter.

The earlier demonstration projects focused on proving that the technology was effective by comparing theoretical dig lists to real-world sources by excavating all of the targets at a given site and comparing the known source results to the predicted source results. More recent projects have focused on actually leaving metal classified as non-TOI in the ground following the completion of the project. An ESTCP/ United States Army Corps of Engineers (USACE)-funded Pilot Study at the former Camp Beale in California and a non-ESTCP-related resulted removal action performed at two sites at the former Camp Sibert resulted in more than 7,000 dynamic target sources remaining un-dug at both sites, with regulator approval. No TOI were

misclassified at either site, and before the addition of quality assurance verification digs, the reduction in necessary clutter digs was above 90% for each.

1.2 OBJECTIVES OF THE DEMONSTRATION

This type of approach has the potential to reduce the number of excavations required to effectively remove the explosive safety risk (MEC) at a given site, which would result in significant cost savings related to the closure of formerly used defense sites (FUDS). The cost savings are expected to be particularly significant at removal action sites such as the WMA, where the current cost of cleanup is expected to approach $1 billion using current removal methods.

1.3 REGULATORY DRIVERS

As part of the cleanup of former Department of Defense sites, buy-in is required from regulatory agencies at the federal, state, and local levels. The advancement in classification sensors and their successful deployment at real-world sites needs to be documented for their use to be accepted by the applicable regulatory agencies. Their acceptance of the use of this technology at sites for which they are ultimately responsible will be particularly important with the potential for Department of Defense budget cuts to affect the amount of money that will be available for future remedial actions.

2.0 TECHNOLOGY

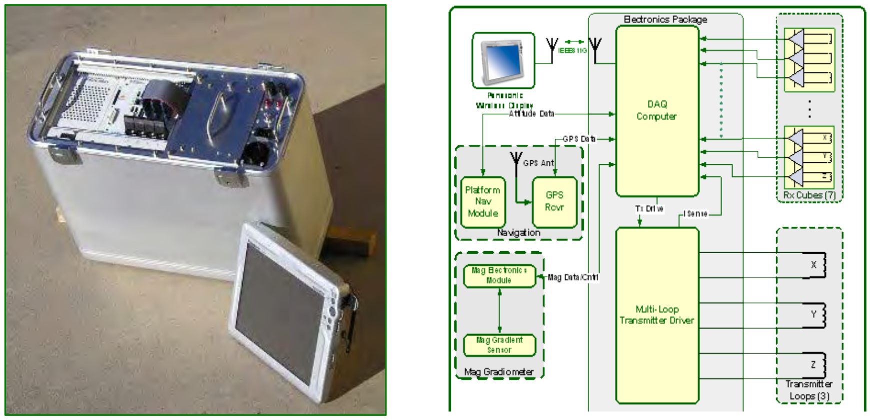
2.1 TECHNOLOGY DESCRIPTION

The MetalMapper is an advanced EMI system developed by Geometrics, Inc., with support from the ESTCP. The MetalMapper draws elements of its design from advanced systems currently being developed by G&G Sciences, Inc. (supported by Naval Sea Systems Command, the Strategic Environmental Research and Development Program, and ESTCP) and by Lawrence Berkeley National Laboratory with support from the Strategic Environmental Research and Development Program and ESTCP. It has three mutually orthogonal transmit loops in the Z, Y, and X directions and contains seven triaxial receiver antennas inside the Z (bottom) loop. Typically, the transmit loops are driven with a classical bipolar pulse-type time domain electromagnetic waveform (i.e., alternating pulse polarity with a 50% duty cycle). Depending on the survey mode (e.g., static/dynamic), the fundamental frequency of transmission can be varied over the range $1.11 \leq f \leq 810$ hertz (Hz). The seven receiver antennas allow 21 independent measurements of the transient secondary magnetic field.

The data acquisition computer (DAQ) is built around a commercially available product from National Instruments. The National Instruments DAQ is a full-featured PC running Windows 7. The DAQ, electromagnetic transmitter, and batteries for the system are packaged in an aluminum case that can be mounted on a pack frame, on a separate cart such as a hand truck, or on the survey vehicle such a tractor. The instrumentation package also includes two external modules that provide real-time kinematic global positioning system location and platform attitude (i.e., magnetic heading, pitch, and roll) data. These modules are connected to the DAQ through serial RS232C ports. A block diagram of the DAQ system is in Figure 2-1.

The MetalMapper has two modes of data collection: dynamic and static. Data collected in dynamic mode results in data files containing many data samples. Generally speaking, dynamic mode data are collected while the antenna platform is in motion. Static mode data collection is employed for cued surveys. As its name implies, the antenna platform remains static or motionless during the period of data acquisition. Depending on the acquisition parameters (e.g., sample period and stacking parameter) it can take tens of seconds to complete a static measurement. The results of the static measurement are written into a binary data file containing only a single data point representing the average (stacked) result, usually over tens or even hundreds of repetitions of the transmitter's base frequency.

Figure 2-1: DAQ and DAQ Functional Block Diagram

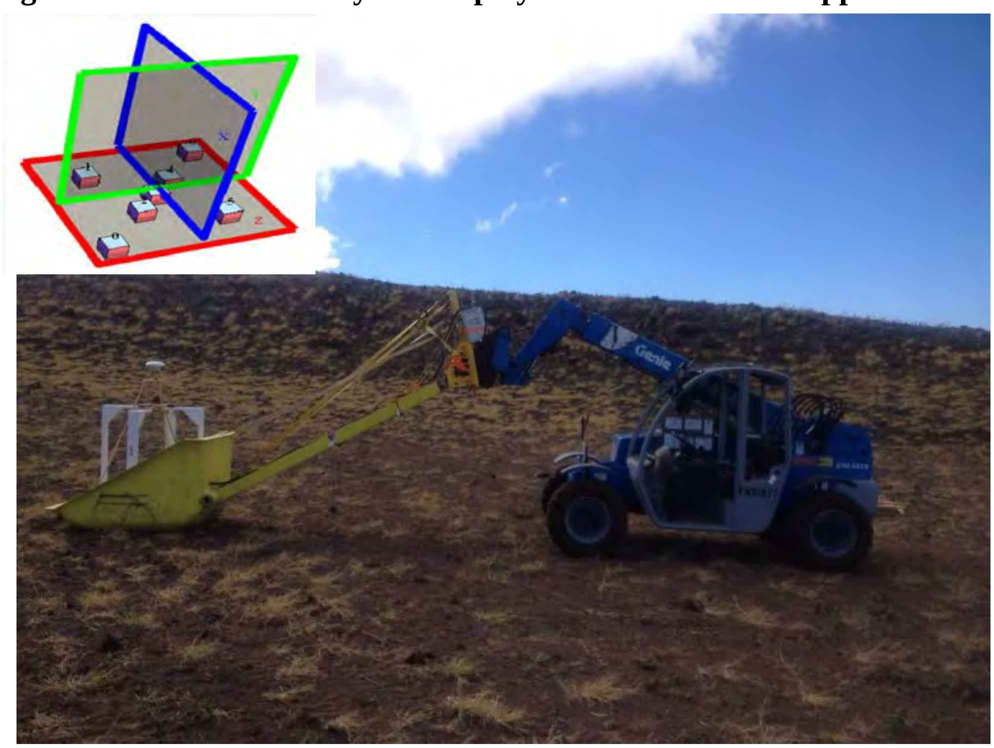


A) MM DAQ assembly with Panasonic terminal.

B) Function block diagram of MM system

Data are acquired in time blocks that consist of a fixed number of transmitter cycle "repeats." Both the period (T) and the repeat factor (N) are operator selectable and are varied in multiplicative factors of 3. The MetalMapper also averages an operator-specified number of acquisition blocks (NStacks) together before the acquired data are saved to disk. The decay transients that are received during the off times are stacked (averaged) with appropriate sign changes for positive and negative half cycles. The decays in an individual acquisition block are stacked, and the decays in that block are averaged with other acquisition blocks (assuming the operator has selected NStack greater than one). The resultant data are saved as a data point. A photo of the typical configuration of the instrument used for collecting both dynamic and cued data is shown in Figure 2-2.

Figure 2-2: Antenna Array and Deployment of the MetalMapper at WMA



In its present (third generation) form, the MetalMapper has been demonstrated and scored at numerous live site demonstrations carried out by ESTCP. The performance of the MetalMapper at these sites is documented in formal reports issued by the various contractors working on those projects.

2.2 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

There are a few advanced EMI sensors that are similar to the MetalMapper in theory, design and size, with the most comparable being the TEMTADS 5x5 and the full-size BUD. The TEMTADS 5x5 consists of 25 pairs of transmit/receive coils oriented in a 5x5 grid pattern, approximately 2 meters (m) to a side. The BUD is composed of three orthogonal transmitters and eight pairs of differenced receivers. These instruments have been part of the ongoing ESTCP classification demonstrations, and similar results have been documented for all three during previous projects. The main advantage of the MetalMapper is that it is currently commercially available, while the other two advanced EMI sensors are generally only used by the organizations that developed them.

The greatest limitation of the MetalMapper is its size, both of the sensor itself and of the accompanying computer, screen, and cables. The system is designed primarily for use in relatively flat, open areas and cannot currently be used effectively in wooded areas, steep terrain, or extremely rocky terrain where the transport vehicles used for the sensor cannot maneuver effectively. The extendable-reach forklift used to transport the system at the WMA (Figure 2.2) was effective in the areas selected for the demonstration, but significant effort was spent identifying even 5.5 acres of relatively flat, somewhat non-rocky ground over which the system could be used at this site. Even after painstaking site selection, it was determined that the base of the bucket in which the MetalMapper sits during data collection would wear down almost daily if dynamic data collection was performed with the MetalMapper, so the decision was made to use the EM61 for the dynamic survey.

In addition to transport issues, the sensor can be extremely difficult to repair in the field. In the case of the WMA project, one of the receivers failed completely (i.e., all three of the tri-axial wrappings) at the beginning of the project. The problem was diagnosed in the field but could not be fixed without sending the MetalMapper computer back to Geometrics for repair. The broken receiver (Rx 0) was one of the outer receivers in the unit, and after consultation with the USACE geophysicist on-site and Black Tusk Geophysics (BTG), it was determined that data collection could continue without repair with the understanding that data from the broken receiver would not be available for use in processing. Various wrappings of the tri-axial receivers have failed on other Parsons projects as well, although all failures have been for wrappings on outer receivers, and the data were not significantly affected as long as the data from the malfunctioning wrapping(s) were not used in inversion. It is assumed this would have been a much larger problem had the issue been with one of the three middle receivers. Data collection could be put on hold for a week or more if the sensor/computer needs to be shipped to Geometrics from a site like WMA, and it is nearly impossible to perform repairs to either the sensor or the computer in the field.

3.0 PERFORMANCE OBJECTIVES

The specific performance objectives for this project are summarized in Table 3-1.

Table 3-1: Performance Objectives for this Demonstration

Performance Objective	Metric	Data Required	Success Criteria
Dynamic Data Collection Objectives			
Repeatability of instrument verification strip (IVS) measurements	Amplitude of electromagnetic anomaly	Twice-daily IVS survey data	Detection: Amplitude within 25%
Static repeatability	Response to standard test object	Twice-daily static measurements of standard object	Response: +/- 10%
Spatial coverage in detection survey	Extended footprint coverage	Mapped survey data	98% coverage
Detection of all targets of interest (TOI)	Percent detected of seeded anomalies	Location of seeded items Anomaly list	100% of seeded items detected with 0.6-m halo
Static Data Collection Objectives			
Repeatability of IVS measurements	Percentage of IVS items identified correctly	Twice-daily IVS survey data	98% of IVS items identified correctly with a confidence metric of > 0.70
Production rate	Number of cued interrogations per day Pre-processing time	Log of field work and data pre-processing time	100 anomalies per day Pre-processing time <3 min per target
Cued interrogation of anomalies	Instrument position	Cued data	100% of anomalies where the center of the cued pattern is positioned within 40 cm of modeled source location

Table 3-1: Performance Objectives for This Demonstration (cont.)

Performance Objective	Metric	Data Required	Success Criteria
Analysis and Classification Objectives			
Maximize correct classification of TOI	Number of TOI retained	Ranked anomaly lists Scoring reports from Institute for Defense Analyses (IDA)	Approach correctly classifies all TOI
Maximize correct classification of non- TOI	Number of false alarms eliminated	Ranked anomaly lists Scoring reports from IDA	Reduction of clutter digs required by >75% while retaining all TOI
Specification of no-dig threshold	Probability of correct classification of TOI and number of false alarms at demonstrator operating point	Demonstrator-specified threshold Scoring reports from IDA	Threshold specified by the demonstrator to achieve criteria above
Minimize number of anomalies that cannot be analyzed	Number of anomalies that must be classified as "Cannot Analyze"	Demonstrator target parameters	Reliable target parameters can be estimated for > 95% of anomalies on the detection list.
Correct estimation of target parameters	Accuracy of estimated target parameters for seed items	Demonstrator target parameters Results of intrusive investigation	Polarizabilities ± 20% X, Y < 15 cm (1σ) Z < 10 cm (1σ)

3.1 REPEATABILITY OF INSTRUMENT VERIFICATION STRIP MEASUREMENTS / STATIC REPEATABILITY

The reliability of the survey data depends on the proper functioning of the survey equipment. This objective concerns the twice-daily confirmation of sensor system performance. The repeatability of instrument verification strip (IVS) measurements was originally specified as the test to measure dynamic instrument functionality; however, the variable geology at the site, the lack of consistently flat areas in which to place the IVS items in each area of interest (AOI), and the relatively short amount of time spent in each AOI (small number of repeated measurements over each IVS with which to compare single tests) were not conducive to the collection of consistent responses over each item. To prove that the EM61 used for the dynamic collection was, in fact, functional each day, a static repeatability test was substituted for the IVS test.

3.1.1 Metric

The metric for the static repeatability test was the measured response for a small bolt versus a standard value determined for the bolt over the course of the project.

3.1.2 Data Requirements

Twice daily measurements of the response generated by the bolt when it was placed in a consistent location relative to the EM61 coil were used to judge this objective.

3.1.3 Success Criteria

This objective was met if the static response for the bolt was within 10% of a standard, expected response. The standard response for the bolt was defined as the average of all of the measurements collected for this item during the course of the dynamic IVS surveys.

3.2 SPATIAL COVERAGE

The detection survey was intended to cover a maximum of the AOI so that all detectable targets were detected. Targets are detectable if the transmitted field is sufficiently strong to reach the target and if the measured target response is sufficiently strong in return to exceed a given threshold.

3.2.1 Metric

The metrics for this objective were collected coverage area versus between-line gaps larger than 70 centimeters (cm) and versus between-line gaps large enough that there was a considerable risk that a TOI might be missed completely (90 cm).

3.2.2 Data Requirements

The percentage of the coverage area with between-line gaps larger than 70 cm and 90 cm were calculated for each day's data using the footprint coverage tool in Oasis montaj's UX-Detect tool.

3.2.3 Success Criteria

This objective was met if more than 98% of each day's coverage area had a line spacing of 70 cm or less and if there were no between-line gaps of greater than 90 cm.

3.3 DETECTION OF ALL TARGETS OF INTEREST

Quality detection data should lead to a high probability of detecting all targets of interest at the site.

3.3.1 Metric

The metric for this objective was the percentage of seed items that were detected using the specified anomaly selection threshold.

3.3.2 Data Requirements

The centers of all seed items were measured using a real-time kinematic global positioning system (GPS) when they were placed in the ground. Dynamic target selections were compared to the known seed item locations as dynamic target lists were submitted, and the horizontal distance was calculated between the seed locations and the nearest dynamic target location.

3.3.3 Success Criteria

The objective was considered met for each seed item if a dynamic target was within 60 cm of the measured seed location.

3.4 CORRECTLY IDENTIFY SEED ITEMS IN THE INSTRUMENT VERIFICATION STRIP

The IVS strip constructed at each AOI contained four inert 37-mm seed items. MetalMapper data were collected over one of the IVSs (dependent on the area being surveyed) twice daily.

3.4.1 Metric

The metric for this objective was the percentage of IVS items correctly classified during the project.

3.4.2 Data Requirements

Daily IVS data were collected and processed in the same manner as all other target points acquired during the project. Following analysis, each IVS target was labeled with an identified source object and a confidence metric that quantified the degree of match between three polarizability curves generated from the measured IVS data and three polarizability curves for a similar item in a target library.

3.4.3 Success Criteria

The performance objective for the project was the correct classification of all IVS seed items with a confidence metric of 0.80 or higher. Due to the potential for the occasional collection of a poor data point without the operator's immediate knowledge, the success criteria was slightly lower than 100%, with the project deemed successful if more than 98% of the IVS data points were classified correctly.

3.5 PRODUCTION RATE

This objective corresponds to data collection and pre-processing time.

3.5.1 Metric

The metrics for this objective are the mean daily survey rate and the mean pre-processing time per anomaly.

3.5.2 Data Requirements

The number of surveyed anomalies and the pre-processing time for each were recorded daily.

3.5.3 Success Criteria

The objective was considered met if the mean daily survey rate is at least 100 anomalies and if pre-processing time is less than 3 minutes per target.

3.6 CUED INTERROGATION OF ANOMALIES

The reliability of cued data depends on acceptable instrument positioning during data collection in relation to the actual source location.

3.6.1 Metric

The metric for this objective was the percentage of sources that were within an acceptable distance of the center of the instrument during data collection.

3.6.2 Data Requirements

The MetalMapper sensor location is determined during the inversion of the collected data and is resolved using the location identified by the GPS sensor directly over the middle of the sensor and pitch and roll data supplied by an inertial movement unit. The sensor location is reported as the X_Array and Y_Array channels in the Geosoft target database. The location of the source object is also calculated during target inversion and was defined as the Fit_X[8] and Fit_Y[8] channels in the Geosoft target database. The distance between these two locations was calculated for cued data point.

3.6.3 Success Criteria

The performance objective was for all single object solver targets to have modeled source locations within 40 cm of the center of the sensor unless a re-shot had already been performed on that target.

3.7 MAXIMIZE CORRECT CLASSIFICATION OF TARGETS OF INTEREST

One of the two main objectives of this pilot study was to show that classification could correctly identify all seeded items and any native items that resembled ordnance that could be considered MEC as TOI. Native items, including practice warheads, motors, and functioned or previously detonated but intact high explosive warheads, were identified as TOI during the intrusive investigation if they resembled a potentially hazardous item to the degree that not investigating such items would present a serious hazard.

3.7.1 Metric

The metric for this objective was the percentage of items classified as TOI following the intrusive investigation that were correctly identified as objects that should be dug in the final ranked dig list.

3.7.2 Data Requirements

Following data collection, MetalMapper data were analyzed to create a prioritized dig list, which assigned each target to one of four categories: 1) TOI 2) Non-TOI, 3) Can't Analyze, or 4) Training. The targets classified as TOI, Can't Analyze, and Training were considered "dig" targets. The list of items identified as TOI following the completion of intrusive operations, including seed items, was compared to those targets marked "dig" in the ranked dig list. If any training items had been identified as TOI upon recovery, the item(s) would have been added to the classification library to identify other similar sources at the site.

3.7.3 Success Criteria

The performance objective was the correct identification of all TOI (including blind seed items) as targets that should be intrusively investigated, or “dig” targets. The project was considered successful if 100% of the TOI were labeled as “dig” targets in the final ranked dig list. No distinction was made between a target correctly identified as TOI and a target identified as a Can’t Analyze point for this objective. Each TOI simply needed to be indicated as a target that should be investigated.

3.8 MAXIMIZE CORRECT CLASSIFICATION OF NON-TARGETS OF INTEREST

This is the second of the two primary measures of the effectiveness of the classification approach. In addition to correctly classifying TOI, the effectiveness of the MetalMapper in discriminating munitions is a function of the degree to which responses that do not correspond to TOI can be eliminated from consideration during the intrusive investigation.

3.8.1 Metric

The metric for this objective was the percentage of items classified as non-TOI following the intrusive investigation that were correctly identified as objects that did not need to be intrusively investigated in the final ranked dig list.

3.8.2 Data Requirements

Following data collection, MetalMapper data were analyzed to create a prioritized dig list, which assigned each target to one of three categories: 1) TOI, 2) Non-TOI, or 3) Can’t Analyze. The targets classified as non-TOI were considered “no dig” or non-TOI targets. The list of items identified as non-TOI following the completion of intrusive operations was compared to those targets marked “no dig” in the ranked dig list. Two thousand targets were intrusively investigated during this project. Therefore, all targets not investigated during the intrusive effort are considered non-TOI.

3.8.3 Success Criteria

The performance objective was considered met if more than 75% of the non-TOI items were correctly labeled as non-TOI while retaining all of the TOI (Section 3.7) above the dig threshold.

3.9 MINIMIZE NUMBER OF ANOMALIES THAT CANNOT BE ANALYZED

Anomalies for which reliable parameters cannot be estimated using the MetalMapper data cannot be classified. These anomalies must be placed in the dig category, which reduces the effectiveness of the classification process.

3.9.1 Metric

The percentage of anomalies for which reliable parameters could not be estimated was the metric for this objective.

3.9.2 Data Requirements

Those targets for which parameters could not be reliably estimated were identified as such on the prioritized dig list submitted following analysis of the MetalMapper cued data.

3.9.3 Success Criteria

The performance objective was considered met if reliable parameters could be estimated for greater than 95% of the targets on the prioritized dig list.

3.10 CORRECT ESTIMATION OF TARGET PARAMETERS

This objective involves the accuracy of the modeled location for target source objects. Both the dig team and stakeholders are more confident that the correct source object is being investigated if the estimated location is relatively close to the recovered object's location, both horizontally and vertically.

3.10.1 Metric

The distance between the inverted target location and the location of the object(s) recovered during the intrusive investigation was the metric for this objective.

3.10.2 Data Requirements

The dig list submitted to the intrusive team contained X, Y locations for each target as determined during inversion of that target. The dig teams measured the offset between any recovered items and the location listed on the dig sheet. The offsets were compared following the completion of the project.

3.10.3 Success Criteria

The project objective was considered met if one standard deviation of the distance between the estimated X, Y locations and the recovery locations were within 15 cm and the estimated depths were within 10 cm (1 standard deviation [σ]).

4.0 SITE DESCRIPTION

4.1 SITE DESCRIPTION

The former WMA is on the northwest side of the Big Island of Hawaii between Waikoloa Village and Waimea. The demonstration was conducted over three AOIs: Task Order (TO) 20 Area A, TO20 Area B, and TO17. A map of the demonstration area and AOIs is shown in Figures 4-1 through 4-3.

4.2 SITE SELECTION

This site was chosen as one in a series of sites for demonstration of the classification process. Sites, including this one, provide opportunities to demonstrate the capabilities and limitations of the classification process on a variety of site conditions. Further information about ESTCP's classification program can be found at http://www.serdp-estcp.org/Featured-Initiatives/Munitions-Response-Initiatives/Classification-Applied-to-Munitions-Response. This site was selected for the program because of its terrain and an opportunity to involve a stakeholder community, including state regulators, in the classification pilot program.

4.3 BRIEF SITE HISTORY

The 100,000-acre former WMA FUDS was acquired by the Navy in 1943 and used as a military training camp and artillery range for 50,000 troops until 1945. Two surface clean-up activities were performed in 1946 and 1954. The 1946 clean-up was done after the departure of the military. The 1954 clean-up followed an accidental detonation of a dud fuse or shell that killed two civilians and seriously injuring three others. Munitions and explosives continue to be discovered at the former WMA. Investigation and clearance continue in areas planned for development and where the risk assessments were rated moderate to high.

To date, more than 100 different types of munitions have been found, including mortars, projectiles, hand grenades, rockets, land mines, and Japanese ordnances. More than 1,800 MEC items, 117,000 pounds of military debris, and 149,000 pounds of munitions debris (MD) have been cleared from 22, 600 acres of the former WMA. The work being performed at the former WMA is being performed under the direction of the USACE Honolulu District.

4.4 MUNITIONS CONTAMINATION

The suspected munitions in the former WMA include:

- 37-mm projectiles
- 60-mm and 80-mm high explosive mortars
- 75-mm, 105-mm, and 155-mm projectiles
- 2.36-in rocket propelled anti-tank rounds
- U.S. Mk II hand grenades
- M1 anti-tank land mines
- Japanese ordnance

4.5 SITE GEODETIC CONTROL INFORMATION

The coordinates for the locations of the existing control points used for this demonstration are provided in Table 4-1. Both control points were set by a survey team from Environet, Inc. (Environet), the contractor currently performing removal actions in TO17 and TO20 at the former WMA.

Table 4-1: Geodetic Control Locations

Identification	Type	Northing (UTM 5N WGS84 m)	Easting (UTM 5N WGS84 m)	Ellipsoid Height (m)
CP13A	Control Point	212907.6	2214682	547.272
CP08	Control Point	205252.2	2211271	32.215

4.6 SITE CONFIGURATION

Three data collection areas, TO17 and TO20 Areas A and B, were selected for data collection during the project (Figure 4-1). The TO17 and TO20 areas were chosen based on the different age of the lava flows that compose the bedrock at each and the desire to evaluate whether the age of the flow would have any effect on geophysical background response. The lava flow underlying the TO17 site near the coast (Figure 4-2) is considerably younger than the flow underlying the two TO20 sites (Figure 4-3). Within each TO area, data collection locations were generally chosen based on relatively flat topography that could be traversed safely with the MetalMapper.

Figure 4-1 Data Collection Boundaries

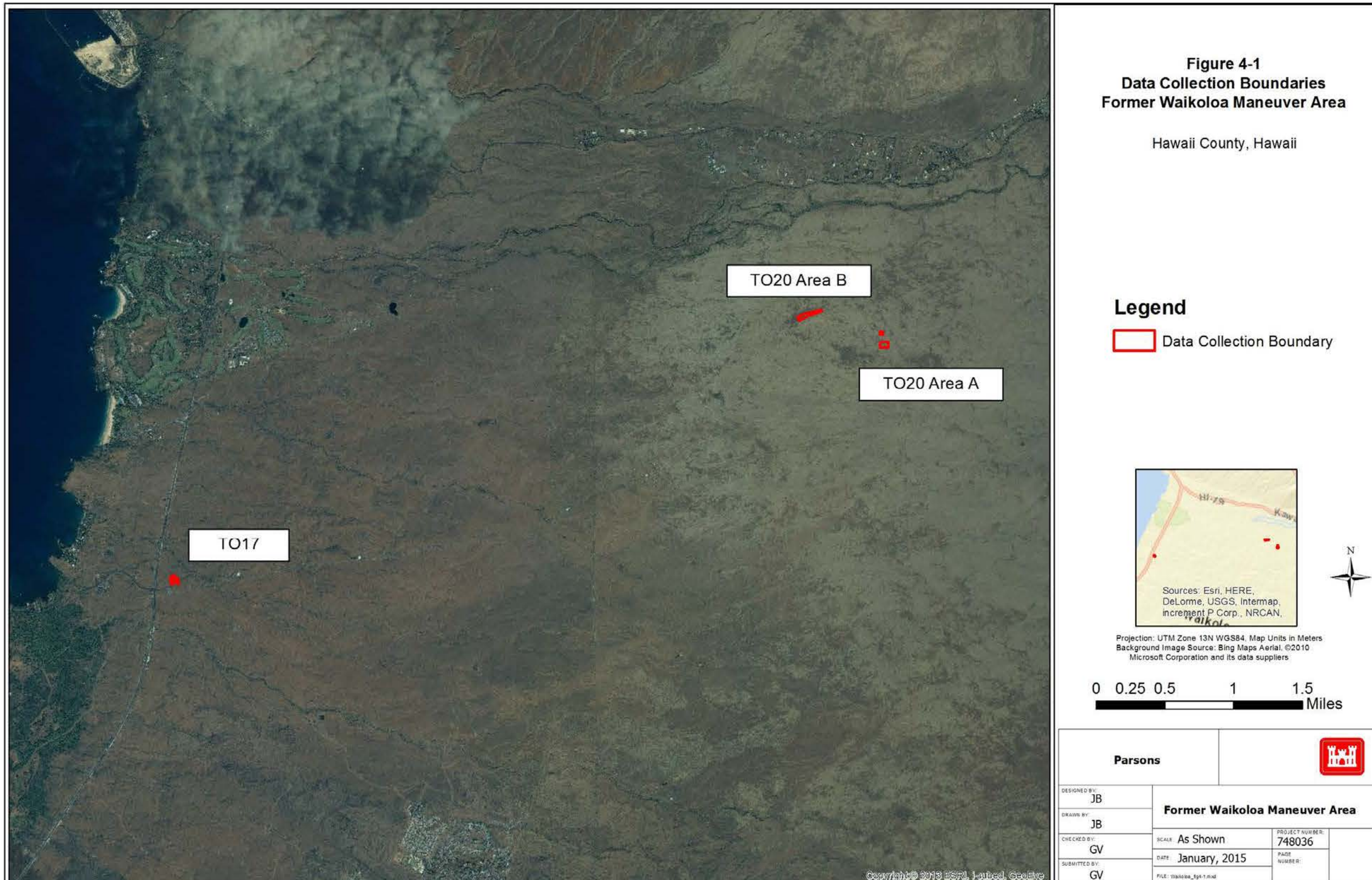


Figure 4-2 Data Collection Boundary, TO17

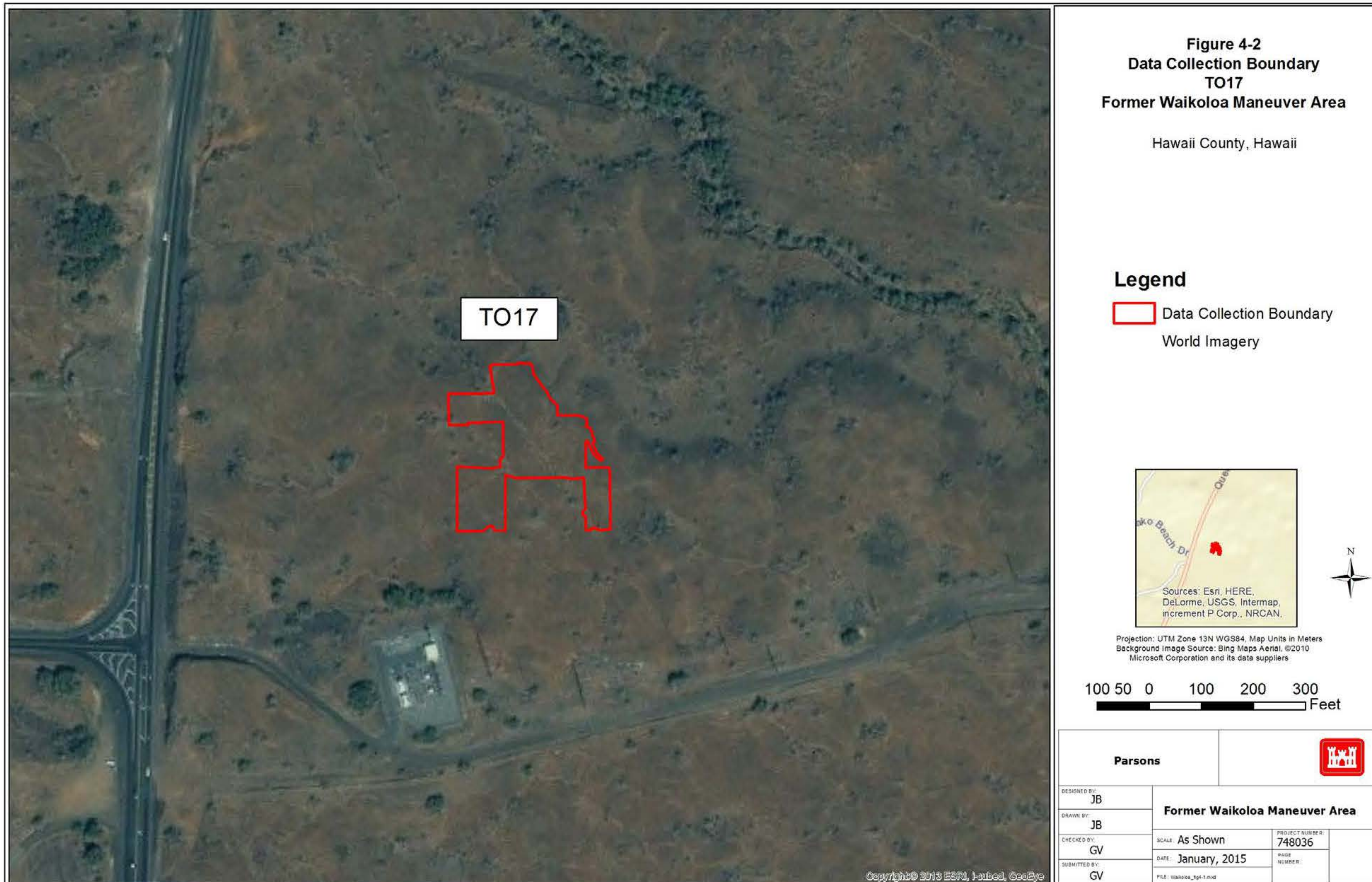


Figure 4-3 Data Collection Boundaries, TO20 Areas A and B

5.0 TEST DESIGN

5.1 CONCEPTUAL EXPERIMENTAL DESIGN

The objective of this program is to demonstrate a method for the use of classification in the munitions response process. The three key components of this method are collection of high-quality geophysical data and principled selection of anomalous regions in those data; analysis of the selected anomalies using physics-based models to extract target parameters such as size, shape, and materials properties; and the use of those parameters to construct a ranked anomaly list. The geophysical data collected over each target were processed using existing routines to extract target parameters. These parameters were passed to the classification routines which, after training on a limited amount of site-specific ground truth, were used to produce prioritized anomaly lists.

Validation digging was coordinated by the Program Office. Because this was a demonstration, all anomalies on the master anomaly list were investigated. The underlying target was uncovered, photographed, located with a cm-level GPS system, and removed. Each analysis demonstrator was able to request ground truth data for training.

At the conclusion of training, each demonstrator submitted an initial ranked anomaly list for each data set analyzed. These lists were ordered from the item the demonstrator was most confident was a munitions through the item the demonstrator was most confident was not hazardous and indicated the threshold the demonstrator chose for initial digging. Anomalies for which the demonstrator could not extract meaningful parameters were placed at the top of the list. The final inputs were scored by the Institute for Defense Analyses, with emphasis on the number of items that are correctly labeled nonhazardous while correctly labeling all TOI.

The primary objective of the demonstration was to assess how well each demonstrator ordered the ranked anomaly list(s) and specified the threshold separating high confidence clutter from all other items. The secondary objective was to determine the classification performance that could be achieved by each approach through a retrospective analysis.

5.2 SITE PREPARATION

5.2.1 Survey of Historical Records

Historical information on this site has been referenced in the stakeholder review draft of the Waikoloa Site Inspection Report, Army National Guard Munitions Response Sites. This report is posted on the ESTCP FTP (file transfer protocol) server and can be used for reference.

5.2.2 First-Order Navigation Points

The two control points used for this project (Table 4-1) were set by a survey team from Environet. The points were originally set using a Universal Transverse Mercator (UTM) Zone 5 Hawai’i North American Datum of 1983 (NAD83) coordinate system, which is approximately 75 cm offset from the UTM Zone 5 World Geodetic System (WGS) 1994 datum used on most geophysical projects. The points in Table 4-1 are in UTM Zone 5 WGS84.

5.2.3 EM61 Transect Survey

A transect survey was performed in TO20 using a single hand-towed EM61, with the intention of determining anomaly densities in areas that would potentially be covered by later 100% coverage dynamic surveys and cued MetalMapper surveys. The transect data were helpful in showing that anomaly densities in most of the sites identified as possible locations for the advanced EMI data collection were relatively low but did not play much of a factor in determining exactly which areas would be selected for additional data collection. Site topography ended up being much more important in the site selection process than anomaly density, although the low densities noted in the transect surveys did lead to the "seeding" of additional non-TOI (scrap from areas adjacent to the data collection area) in TO20 Area B.

5.2.4 Surface Clearance

A surface sweep was performed by UXO technicians from Environet before starting any geophysical operations. Typically, surface sweeps are undertaken to remove larger metallic debris on the ground surface that would interfere with data collection or to remove all metallic debris in cases where the quantity of such debris would significantly affect the collected data. In the case of the former WMA sites, anomaly densities were low enough that leaving debris present on the ground surface did not present a concern with regard to elevated anomaly densities. Given the rocky nature of the sites and the relatively thin soil layers present, it was actually suspected that most metallic debris present on site might have been on or very close to the surface. So the surface sweep performed for the project was only intended to clear the area of any surface munitions that would present a possible hazard to the team conducting the 100% coverage dynamic survey and the cued MetalMapper data collection. All nonhazardous debris was left in place.

5.2.5 Seeding Operation

At a site such as this, there is usually a high ratio of clutter to TOI. To determine classification performance with acceptable confidence bounds, the site was seeded with enough TOI to ensure reasonable statistics.

Parsons' subcontractor Environet conducted seeding operations at WMA from August 28, 2013, through September 4, 2013, and on September 17, 2013. Medium and small industry standard objects (ISOs), inert 37-mm projectiles, inert 60-mm mortars, and inert 81-mm mortars were buried throughout the survey area as quality control (QC) blind seed items before the start of detection survey data collection. The location of each seed item was established with a Trimble R8 real-time kinematic GPS system. Seeds consisted of 7 medium and 10 small ISOs, 48 inert 37-mm projectiles, 20 inert 60-mm mortars, and 12 inert 81-mm mortars. The items used as seeds were borrowed from the USACE and Naval Research Laboratory and were returned at the end of the project.

Environet practiced anomaly avoidance at each location for safety and to ensure a clean area for emplacement. Despite hard ground conditions at the three AOIs, all 97 seeds were placed at the depths specified in the seeding plan. Excavation of the seed holes involved manual digging to meet exact depth/orientation specifications and to minimize burial evidence. A photo was taken of the seed item at the burial location and included a whiteboard showing all emplacement information.

Seed location holes were not backfilled until final QC checks were complete. QC checks consisted of comparing the location with the original designated location; capturing the center location of the emplaced seed item with GPS; and checking the depth, inclination, and dip angle of each seed item. After these checks were complete, the hole was backfilled with a shovel to prevent any excess movement of the seed items. Table 5-1 lists the seed items emplaced for the project.

Table 5-1: WMA Demonstration Seed Items

Seed Item	Total
Small ISO	10
Medium ISO	7
37 mm	48
60 mm	20
81 mm	12
Total	97

5.2.6 Establish an Instrument Verification Strip

A relatively clean area for use as the IVS was identified in or near each AOI. Based on a lack of available seed items, all IVS items were the same four inert 37-mm projectiles that were moved from AOI to AOI as the MetalMapper was moved. The projectiles were buried horizontally at a depth of 10 cm at approximately 5-m intervals in each AOI except in TO17.

5.3 SYSTEM SPECIFICATION

The MetalMapper sensor and data acquisition system are described in detail in Section 2.1. During the demonstration study, the antenna array was transported via a sled mounted to the front of an extendable reach forklift (Figure 2-2). A Trimble R8 GPS was mounted directly above the sensor array using a wooden tripod, and an inertial measurement unit was attached to the wooden support used to stabilize the X- and Y-direction transmitters, also directly above the center of the array. These instruments streamed positional data constantly at a rate of 5 Hz. The two instruments were connected to the DAQ via universal serial bus ports. Incoming GPS data were used both to navigate from point to point and to locate the collected response data. Inertial movement unit corrections are not performed in real time and integrated with the incoming GPS data on the MetalMapper screen, but they were used to correct the locations of all collected GPS points based on the pitch, roll, and yaw information recorded with the GPS measurements.

5.4 CALIBRATION ACTIVITIES

5.4.1 Test Pit and Instrument Verification Strip Data Collection

A test pit was constructed at the site before the start of cued MetalMapper data collection. The pit was an approximately 3-foot by 3-foot by 3-foot hole that allowed the collection of static MetalMapper data over TOI items expected at the site. The test pit data could then be used for comparison with field data collected over unknown targets. Test pit items were various depths in

the hole during collection to determine the effects of depth on MetalMapper response, and data were collected over the items oriented horizontally and vertically at each depth. In addition to the data collected over items in the test pit, a test stand was set up to collect data over smaller munitions that had been found by Environet over the course of their work at the site. As with the test pit data, test stand data were collected with the items at various distances below the sensor and at different orientations. Test pit data were collected on August 29 and 30, and test stand data were collected on September 6. The items tested and the depths and orientations used for testing are indicated in Table 5-2.

Table 5-2: MetalMapper Test Pit/Test Stand Data Collected

Item Identification	Depths (cm)	Orientations
Test pit data (8/29/13 and 8/30/13)		
37-mm projectile, 4.5-in long, rotating band	0, 10, 20, 25	Horizontal, vertical (each depth except surface [horizontal only])
37-mm projectile, 3.5-in long, rotating band	0, 10, 20, 30	Horizontal, vertical (each depth except surface [horizontal only])
37-mm projectile, 4.5-in long, no rotating band	0, 10, 20, 30	Horizontal, vertical (each depth except surface [horizontal only])
60-mm mortar, warhead only, training	0, 10, 30, 40	Horizontal, vertical (each depth except surface [horizontal only])
60-mm mortar, with tail	0, 10, 30, 40	Horizontal, vertical (each depth except surface [horizontal only])
60-mm mortar, 9.25-in, hollow, with tail	0, 10, 25	Horizontal, vertical (each depth except surface [horizontal only])
60-mm mortar, 7-in, hollow, with tail	0, 10, 30	Horizontal, vertical (each depth except surface [horizontal only])
60-mm mortar, 5-in, hollow, no tail	0, 10, 30	Horizontal, vertical (each depth except surface [horizontal only])
81-mm mortar, with tail	0, 25	Horizontal, vertical, 60 degrees nose up, and 60 degrees nose down
Test stand data (9/6/13)		
M48A2 fuze	16.5, 20	Horizontal, vertical (nose up) (each depth)
M48 unknown mod fuze	16.5, 20	Horizontal, vertical (nose up) (each depth)
M54 time fuze, superquick element	16.5, 20	Horizontal, vertical (nose up) (each depth)
M58 37-mm base fuze	16.5, 20	Horizontal, vertical (nose up) (each depth)
M63 37-mm high explosive projectile, version 1	16.5 20 25	Horizontal Vertical Horizontal
M63 37-mm high explosive projectile, version 2	16.5 20 25	Horizontal Vertical Horizontal

In addition to the test pit and test stand data, data were collected over the IVS twice daily during the cued survey. All data collected over the IVS strip were processed as described in Section 6.2

and compared to either expected responses (EM61) or the WMA target library (cued). The following tests were performed for the collected IVS data:

- Dynamic: It was intended that dynamic responses measured over seed items in the IVS strip be within 25% of the expected response for each item. However, due to site conditions (i.e., geology, rocky terrain) and because the data collection crew was never at an AOI for more than a couple of days, the IVS surveys proved to be too inconsistent to pass this metric. IVS items were consistently detected with responses that would have led to their selection as targets in a dynamic data set, but over the course of the relatively few passes collected over the IVS at each site, they were generally not all within 25% of the average value for each IVS. It is suspected that small changes in the path over the items and the widely variable geology at the site were the major causes of inconsistent responses. Daily static tests were substituted for the IVS testing to ensure that the EM61 used for the dynamic data collection was functional and that readings were consistent over the course of the project. The static test involved the collection of 1 minute of data with no source present and 1 minute of data with a small bolt placed in the center of the EM61 coil. The mean response for the test with the bolt subtracted from the mean background response to determine the response caused by the bolt. All responses measured during the project were averaged to determine an expected response for the bolt, and each individual measured response was expected to be within +/- 10% of the expected response to ensure that the system was in working order. As long as the EM61 was not moved between the background and bolt tests, this ensured that geology and bumps over rocks did not alter the measured response.
- Static: The item identified by the target library comparison was compared to the actual buried item, and it was expected that the identified item matched TOI with a confidence high enough that it would be marked as a dig (0.7 confidence > 98% of the time).

IVS testing results are detailed in Section 7.1.

5.4.2 Background Data

Background data were generally collected every 2 hours throughout the project. MetalMapper background collection points were determined by the operator who searched for a clear location using the “dancing arrows” display on the computer screen. Although this has been an acceptable way to collect background data at other sites, it was a more questionable practice at WMA given the magnetic geology at the site that produced a much more significant response than typically seen at other demonstration sites. In addition to a the magnitude of the response, it was also highly variable across the site, with lateral changes of a few feet or vertical changes of a few centimeters resulting in significantly different background values. Vertical changes, or the difference between the height of the instrument above the ground surface during collection of a background location (typically closer to 15 cm or the height of the sensor when placed on flat ground), were actually fairly common given the rocky nature of the site, because the instrument could not be placed directly on the ground surface at target collection locations. Given the extremely variable geology at the site, two background points were collected at each background location, one on the ground surface and one approximately 3 feet in the air, assuming that being able to remove the effects of consistent environmental factors (e.g., forklift, electronics, atmospheric conditions) might prove useful rather than having to depend on inconsistent background conditions.

BTG dealt with the variable background data in different ways. The data were corrected using typical methods with the background collected at the site, and inverted as described in Section 6.2. In addition, given the uncertainty of local background measurements, BTG also developed a background model based on correction of the on-ground background data using the in-air background data. The model treated the background response as a plate-like target at a 95-cm depth directly below the middle of the sensor. As with the data corrected using the site backgrounds, BTG performed various inversions for each target. One of these was a three-source inversion in which one of the three sources was constrained to be its model of background. BTG also performed an un-background-corrected two-source inversion in which it was assumed that one of the two modeled sources would be local background, with the other being the selected EM61 source.

5.5 DATA COLLECTION PROCEDURES

5.5.1 Dynamic Data

Dynamic data were collected by hand-pulling or carrying (stretcher mode) the EM61 across the project site along parallel lines spaced 50 cm apart. The EM61 had a GPS antenna directly over the center of the sensor, which transmitted real-time positioning data to the data logger. The EM61 GPS data at TO20 Area B were collected using the NAD83, Hawaii datum, which is significantly different from the WGS84 datum automatically assumed by the MetalMapper, which led to a significant shift (~75 cm) between the target locations as shown on the MetalMapper screen during collection and the actual source locations in the ground. Sources were generally to the southwest of the indicated location, and the MetalMapper team generally started looking for the source for a particular target to the southwest of the on-screen location at this site. A modified intrusive process was developed for TO20 Area B, as described in Section 5.6, to ensure that no metallic sources were missed as a result of the datum shift. The datums were synchronized for the TO20 Area A and TO17 data collection.

5.5.2 Cued Data

The operator moved the array by lifting the sled, navigating to the vicinity of each selected point using the graphic display on the computer monitor, and setting the MetalMapper down on the point. Reacquisition of the EM61 targets selected for cued data collection was accomplished using dancing arrows display on the monitor. This display shows the seven receivers in the array, arranged as they are in the Z-coil, typically with a blue arrow pointing out of each. The arrows point toward the metallic source nearest each of the receivers. Under ideal conditions, there is one source in the vicinity of the selected point, and all of the arrows point inward toward the center of the array. In the case of multiple sources, one or more of the outer arrows may point outward from the array toward another piece of metal. Generally, the operator attempted to position the array such that, at least, the arrows in the three receivers closest to the middle of the coil were pointing at each other. After the MetalMapper was positioned correctly above the target, the operator collected a data point using the settings indicated in Table 5-3.

Table 5-3: Cued Data Acquisition Parameters

Mode	Tx Mode	Hold-Off Time (μs)	Block Period(s)	Rep Fctr	Dec Fctr (%)	Stk Const	Base Freq (Hz)	Decay Time (μs)	No. Gates	Sample Period (s)	Sample Rate (S/s)
Static	ZYX	50	0.9	27	10	10	30	8328	50	9	N/A

An in-field QC program developed by BTG was also used during the project to check on the location accuracy of the collected point. The QC program performed a rapid inversion of the collected data and identified the inverted source location relative to the collection point on the MetalMapper screen. If the inverted location was more than 30 cm from the collection point, the operator moved the sensor over the inverted source location and collected another point.

Static targets were identified according to the identification (ID) determined for each target picked in the dynamic EM61 survey. For repeated measurements taken based on the results of the in-field inversion, 10,000 was added to the original ID (e.g., the re-shot for 0001 was 10001). For repeated measurements taken based on a comparison of data collection location to inverted source location in following data processing, 50,000 or 60,000 (for multiple re-shots) was added to the original ID.

5.5.3 Scale of Demonstration

Dynamic data were collected over 5.3 acres of the WMA site. A total of 1,048 targets were identified in the dynamic data for further evaluation via the cued survey. The cued survey covered 1,288 data points for 1,032 targets. The remaining 16 targets were not collected due to time constraints, although Parsons did ensure that data were collected over all seed items before departing the site. The 256 extra points were re-shots of already collected points due to a high offset between the location of the center of the MetalMapper and the location of the inverted source determined either using the in-field QC program (> 30-cm offset) or processed data (> 40-cm offset).

5.5.4 Sample Density

One data point was collected per target, as described in Section 5.5; re-shots were collected for targets with initial collection locations greater than 40 cm from the inverted source location.

5.5.5 Data Quality Checks

An instrument calibration check was conducted a minimum of twice a day (at the beginning and the end of the field day) at the IVS. These checks are performed to ensure that the MetalMapper is functional, properly calibrated, and stable. Failure with regard to the performance objective (Section 3.4) generally indicates a problem with either the MetalMapper and its associated hardware/software or the data collection method for the failing point. As discussed in more detail in Section 7.4, given the varying background conditions at this particular site, IVS failures were not considered a sign of a problem with either the equipment or the data collection process.

An in-field check on the data collection location versus modeled source location was also performed for each data point collected. This was accomplished using a program that performed a rapid single object inversion of the collected point to determine a source location. Points with

sources modeling farther than 30 cm from the initially collected point were re-collected at the indicated inverted source location.

5.5.6 Data Handling

Data were recorded in binary format as files on the hard disk of the MetalMapper DAQ. These data were offloaded to other media at least once per day. The computer's hard disk had enough capacity to store all data from the entire site, so these data were not erased until they had been thoroughly reviewed and archived. The data file names acquired each day were cataloged and integrated with any notes or comments in the operator's field book. All data ended up on the hard drives of one or more laptop computers and were also archived to a data server in the Parsons office. All .tem files collected were transferred via FTP for processing by BTG.

5.6 INTRUSIVE PROCEDURES

Parsons' intrusive operations at WMA began on February 3, 2014, and ended on February 13, 2014. Operations began with the site-specific training, which included prepping the staging area for intrusive activities and performing equipment checks. All Parsons intrusive equipment was stored off site in a secure location that was locked at the end of the day. Daily equipment check included confirming GPS accuracy over known control points, EM61 static tests, and handheld analog instruments Minelab Explorer SE calibrations.

The intrusive investigation was performed before submittal of a full ranked dig list, although BTG did perform an initial determination regarding whether it was more likely that the dynamic anomaly for a given target was due to an actual metallic source or to changing background conditions. In addition, due to the 75-cm discrepancy between the two location datums used during the project (NAD83 Hawaii and WGS84), there was some concern that the MetalMapper points collected in the TO20 Area B AOI might not have been collected over the intended dynamic target. To ensure that both the dynamic target source and the sources classified by the MetalMapper (i.e., whatever was under the MetalMapper during collection whether it was the dynamic target or not) both targets were added to the dig list if they were more than 50 cm apart and the source identified by the MetalMapper did not appear to be geologic in nature. The type of point to be investigated, EM61 dynamic target or MetalMapper target, was identified by suffixes added to the target ID. Targets with an "A" suffix were MetalMapper targets and indicated sources that appeared to be caused by a metallic object rather than geology. "A" targets were not generated for a given target ID if the MetalMapper data indicated that there was no metallic source present in the collection location. Targets with a "B" suffix were EM61 dynamic target locations that were either more than 50 cm from a metallic MetalMapper source or dynamic target locations where the MetalMapper data did not indicate the presence of a metallic object. "B" targets were not generated if the dynamic target location was within 50 cm of the location of a metallic source per the MetalMapper data. Any suffixes above "B" (e.g., "C", "D") were MetalMapper repeat shots that indicated the presence of a metallic object different from the one present in the "A" location.

All intrusively investigated anomalies were documented per the demonstration work plan. Seed items intrusively investigated were stored in a separate bin and inventoried daily. After all the seed items were accounted for, they were shipped off site.

Personnel on site to conduct the intrusive operation included Parsons and Environet, the UXO explosives subcontractor. The field team consisted of a senior UXO supervisor, a site safety and

health manager, four Parsons personnel, and two Environet personnel. Parsons' site safety and health manager and the Parsons' site manager conducted daily site safety briefings, as appropriate.

5.6.1 Equipment

The equipment used during the former WMA intrusive activities included the following:

- Minelab Explorer SE
- EM61-MK2
- Trimble R8 GPS system
- Miscellaneous hand tools
- Digital cameras

5.6.2 Field Procedures

Reacquisition of all targets was conducted using the Trimble R8 GPS system. For TO20 targets, the GPS base station was set up on survey monument CP13A and checked daily on monument P013chin. For TO17 targets, the GPS base station was set up on survey monument CP012 and checked daily on monument CP8. Parsons flagged all target locations with a metal pin flag marked with the target identification and EM61 pre-value. The Minelab Explorer SE was used to determine the initial approach to every target and as a screening process to determine if metal was present in the subsurface or if the anomaly was caused by the local geology. If the Minelab Explorer SE indicated that there was no metal present in the area, the anomaly was considered a "no contact." A GPS point was then taken at the location of the flag and a photograph was collected of the area surrounding the flag. If the Minelab Explorer SE indicated that there was metal present in the subsurface, the UXO technicians would carefully excavate the item. Location data captured by GPS were used to document the center mass and depth of each item. A photograph was collected of the item with written dig result data on a whiteboard. Lastly, an EM61 unit was used to scan the location to confirm the absence of all metallic items from that target location or that the pre-millivolt reading had been reduced by at least 75%.

The Parsons team leader who orchestrated the movements of the different tasks associated with the information-gathering process recorded all documentation on a dig sheet. The intrusive operations consisted of one intrusive team that was responsible for reacquisition, intrusive, and anomaly documentation. After enough target locations were flagged, the intrusive team would split into two teams to expedite the process.

All seed items recovered from intrusive operations were stored in a secure area and prepared for final shipment. Twenty-eight inert 37-mm projectiles and six inert 60-mm mortars were shipped on February 25, 2014, to U.S. Army Engineering & Support Center in Huntsville, Alabama. Twenty-five inert 37-mm projectiles, fifteen inert 60-mm mortars, and twelve inert 81-mm mortars were shipped on February 25, 2013, to the Army Research Lab in Welcome, Maryland.

Excavated holes greater than 30 cm deep were left open for the site archaeologist to investigate further if need be. All other target locations were backfilled after completion of the excavation. After the final anomalies were excavated and backfilled, Parsons conducted a walkthrough and confirmed that all holes were filled and no trash was left.

Excavation data collected by the intrusive team was digitally downloaded to a database and reviewed daily. The daily information required the target ID to be connected with intrusive documentation, photo, and GPS coordinates. Assessment of each target item required the coordinates to match the original location and the picture to match the documented findings. Results of the intrusive investigation are shown in Table 5-4. Photographs of the intrusive operation are shown in Figure 5-1.

Table 5-4: Intrusive Results

Type	Items	Percent
TO20A (1.7 acres)		
Other Debris	3	0.8
Munitions Debris	90	24.6
No Contact	244	66.6
Seed	29	8.0
Total	366	100
TO20B (2.4 acres)		
Other Debris	630	53.9
Munitions Debris	453	38.8
No Contact	50	4.3
Seed	35	3.0
Total	1,168	100
TO17 (1.2 acres)		
Other Debris	3	0.9
Munitions Debris	45	13.0
No Contact	258	74.6
Seed	40	11.5
Total	346	100
Overall Results (5.3 acres)		
Other Debris	636	33.8
Munitions Debris	588	31.3
No Contact	552	29.4
Seed	104	5.5
Total	1,880	100

5.7 MUNITIONS DEBRIS MANAGEMENT

MD and other debris (OD) scrap recovered from the demonstration area at WMA amounted to more than 310 pounds. The MD/OD scrap was stored in a locked storage area. Parsons’ senior UXO and site safety officer certified all MD scrap by thoroughly going through each piece individually before scrap was transferred to Environet for final disposition.

Figure 5-1: Intrusive Operation Photos


DATE: 2-3-14
ANOMALY: WK-1029A
DEPTH(cm): 36
ID: 60mm
LENGTH(cm) 13
DIG TYPE: SEED

6.0 DATA ANALYSIS AND PRODUCTS

The MetalMapper was used to collect static data for 1,031 targets identified at WMA based on the 5.3 acres of EM61 data. The processing and analysis steps that were used to generate a dig/no dig decision for each target are described below.

6.1 DYNAMIC DATA

The geophysicist processing the EM61 data merged the positioning and geophysical sensor data to assign positions for each data point. The located data points were exported to an ASCII format file, which was then imported into the Geosoft Oasis montaj geophysical data processing environment. Once in Oasis montaj, the data from the third time gate were leveled using a 150-point median statistics filter. The leveled data were gridded and displayed on a map, latency corrected to remove any evident chevron patterns, then re-gridded and displayed for target selection.

Targets were selected using the Blakely test algorithm in the UX-Detect package in Oasis montaj with a threshold of 5 millivolts. The Blakely test selections were then reviewed by the processor, who merged target picks on the same anomaly or added picks to unpicked peaks evident on the color-shaded grid map. After the target list for each dataset was finalized, the targets were forwarded to the MetalMapper team for cued collection.

6.2 CUED DATA

All cued data processing, analysis, and classification was performed by BTG. Appendix A contains a BTG report detailing the analysis process for the WMA cued data. Appendix B contains a BTG memorandum primarily focused on seed items incorrectly classified as either clutter or soil, although it also briefly describes the process used to compile the dig list submitted for the site.

7.0 PERFORMANCE ASSESSMENT

7.1 REPEATABILITY OF INSTRUMENT VERIFICATION STRIP MEASUREMENTS

As discussed in Sections 3.1 and 5.4.1, the planned dynamic testing with the EM61 proved ineffective given site conditions (i.e., geology, terrain, lack of time spent in each AOI). Twice-daily static tests were substituted for the IVS testing to ensure that the EM61 used for the dynamic data collection was functional and that readings were consistent over the course of the project. A small bolt was placed in the center of the EM61 coil for this test, and all measured responses for the bolt were expected to be within 10% of the average response calculated over the entire project. All measured responses were within 3.5% of the average, indicating that the EM61 maintained consistent readings throughout the project.

Given the troubles with the dynamic testing performed, it would make sense to pre-plan a standard IVS location for any future dynamic work conducted at the former WMA. The IVS should be located in a flat area free of rocks and accessible consistently at the start and end of each day rather than depending on where the field team is working on a given day. Ideally, an area with relatively constant geologic response could be identified, although responses for seed items would likely be consistent in changing geologic conditions as long as the EM61 is not bouncing over rocks during collection.

7.2 SPATIAL COVERAGE

Most of the dynamic datasets passed the primary coverage objective and covered more than 98% of their respective areas with a 70-cm or less spacing. The notable exception was on the west side of TO20 Area B, where there were a significant number of gaps due to a faulty GPS. Had the dynamic survey been performed with the MetalMapper as intended, these gaps would have been filled in to achieve the desired coverage. However, following the change from the MetalMapper to the EM61 for dynamic data collection, proving the technology for metrics that would potentially be used for future advanced sensor dynamic surveys became less important. More emphasis was placed on collecting enough dynamic data to identify 1,000 discrete targets for the follow-on cued survey than spending time filling in gaps. Additional EM61 data were collected to fill in gaps over seed items as necessary and as possible. Even with the gap fills, some seeds were buried so far outside of the final dynamic survey areas that it was extremely impractical to collect any data over them. In these cases, the seeds were simply added to the cued collection list using the locations determined during seeding operations.

7.3 DETECTION OF ALL TARGETS OF INTEREST

No dynamic survey target was selected within 60 cm of six of the seed items placed at the former WMA. The majority of the missed seeds (five of the six) were in TO17, where geologic response was far more variable than either of the other two sites. The final missed seed was in TO20 Area B. Despite the offsets, the MetalMapper operator was able to correctly locate two of the six with enough accuracy to collect a MetalMapper point within 40 cm of the seed item. Table 7-1 indicates which seeds were missed and comments on the reasons for the misses.

Table 7-1: Seeds without Dynamic Target within 60 cm

Seed ID / Nearest Target	Description	Depth (cm)	Seed to Target Offset (cm)	Reason for Miss
WSO-06 / 50	81-mm mortar	60	74	Possibly GPS datum offset; possibly geology. MetalMapper point collected within 40 cm.
WSO-67 / 885	37-mm projectile	24	70	Nearby geologic response greater than response from seed.
WSO-73 / 943	37-mm projectile	16	82	Nearby geologic response greater than response from seed.
WSO-93 / 810	37-mm projectile	15	65	Geologic response in area greater than response from seed. MetalMapper point collected within 40 cm.
WSO-94 / 787	60-mm mortar	37	63	Geologic response in area greater than response from seed.
WSO-98 / 885	37-mm projectile	15	895	Not within EM61 survey area. Apparently added to target list in incorrect location.

7.4 CORRECTLY IDENTIFY SEED ITEMS IN THE INSTRUMENT VERIFICATION STRIP

All IVS seeds used during the project were 37-mm projectiles buried at a depth of 10 cm, and a total of 57 measurements were taken over IVS items during the project. Parsons analyzed the IVS data while on site, using both in-air and ground-based background measurements to correct the IVS data points. Use of the ground-based background correction data typically provided better results than the in-air points, although even those results were not ideal. While the IVS data generally matched some item in the library well (> 0.9 confidence metric), a correct match to a 37-mm projectile was inconsistent. A total of 24 of the 57 measurements returned either a 37-mm projectile or small ISO result with a confidence metric above the required 0.8. The remaining results generally trended toward larger ordnance such as 60-mm mortars, seemingly indicating that background at the seed locations was adding more response than was being removed by the background correction. This was confirmed by the use of the in-air background measurements for point correction, which removed less background response from the IVS points. Library matches for the points corrected with the in-air data were consistently larger than a 37-mm projectile, and the smallest result returned for these data was a 57-mm projectile. In addition to the mismatches with regard to seed size, 4 of the 57 IVS results failed to match anything in the library with a confidence metric greater than 0.8.

Given the known issue of significant background variance across the site, the IVS failures were not considered problematic with regard to the equipment in the field. It was known almost from the beginning of the project that the standard background correction and UX-Analyze library matching processes Parsons typically uses for classification were not going to be effective for this site. Therefore, the IVS data were considered sufficient to show that the MetalMapper was in working order.

7.5 PRODUCTION RATE

MetalMapper data were collected over 1,031 discrete dynamic target locations over 16 days of MetalMapper use, which corresponds to a daily rate of approximately 64 points per day.

Included in the 16 days were 2 full days spent either fixing the MetalMapper or moving it from one AOI to another (i.e., MetalMapper use but no data collection). If only data collection time is considered, the production rate was closer to 74 points per day, which is still below the goal of at least 100 points per day.

The lower-than-expected production rates were entirely due to site conditions, primarily topography and the effects of geology on the MetalMapper. Transition of the MetalMapper from point to point was slowed by rocky topography, which took time to navigate safely. In addition, changing geologic response made finding subsurface sources using the dancing arrows display on the MetalMapper screen extremely difficult and time consuming. There were also many cases where it became clear following data analysis and the intrusive effort that numerous dynamic targets were selected due to elevated geologic response rather than an actual subsurface source, so a great deal of time was spent searching for nonexistent targets. While BTG's in-field QC software was used along with the dancing arrows and was helpful in getting the MetalMapper positioned over actual subsurface sources, its use also resulted in a significant number of re-shots. A total of 1,288 points were collected over the 1,031 dynamic targets on the cued target list, corresponding to a re-shot rate of nearly 25%.

Parsons cued data collection production rates on most other Military Munitions Response Program sites are upwards of 300 points per day, so the production rates measured at the former WMA are a significant decrease. However, nothing has been factored in to the WMA production rates that seems like it could be easily modified to vastly increase production rates on a larger-scale project.

The Demonstration Plan for the project also indicated that pre-processing time for each target should be less than 3 minutes. Pre-processing time, considered to be the amount of time needed to get the .tem files collected by the MetalMapper into a format usable by post-processing software such as Geosoft or MATLAB, is a matter of minutes for a day's worth of data using currently available software. This metric can be safely removed from consideration for future projects.

7.6 CUED INTERROGATION OF ANOMALIES

An initial modeled location for each MetalMapper target was determined using an in-field QC program, and a re-shot was collected for any target for which the source modeled farther than 30 cm from the collected point. No additional re-shots were collected if a source did not model underneath the first re-shot location. The field team did not have sufficient time to re-shoot any targets that did not have sources within 40 cm of the collected location despite the appearance of a modeled source within 30 cm of the collection point in the field (i.e., the final model did not agree with the in-field model).

7.7 MAXIMIZE CORRECT CLASSIFICATION OF TARGETS OF INTEREST

Nine seed items placed within the demonstration areas were incorrectly classified as either clutter or soil response on BTG's final dig list. One of these, target 73 (37-mm projectile) did not have a MetalMapper point collected within 40 cm of its actual location. The nearest MetalMapper point was 74 cm offset, so the "soil response" classification is likely correct. For the remaining eight misses, BTG concluded that the effects of the background response due to site geology were too significant to allow the correct classification of these targets regardless of processing method. Therefore, the project failed the performance objective of correctly

identifying all TOI at the site. BTG's memorandum describing the incorrect classification of the seeds and their conclusion that all targets at the site needed to be dug to recover all of the TOI is included as Appendix B.

7.8 MAXIMIZE CORRECT CLASSIFICATION OF NON-TARGETS OF INTEREST

Because BTG concluded that all targets at the site needed to be excavated to ensure the recovery of all of the TOI (Appendix B), the project failed the performance objective of reducing clutter digs by more than 75%.

7.9 CORRECT SPECIFICATION OF NO-DIG THRESHOLD

BTG's stop-dig point in their submitted dig list was at target 295 of 939 (Appendix B). The eight seeds classified incorrectly on this list were scattered between spots 370 and 692 in the list. As a result, the stop-dig point was specified incorrectly. Because the misclassifications were caused by geologic response drowning out the signal from the seed items, BTG concluded that there was no method of reprocessing the data that would result in the missed items being moved up on the dig list to the point that a new stop-dig threshold would be effective in significantly reducing clutter digs at the site.

7.10 MINIMIZE NUMBER OF ANOMALIES THAT CANNOT BE ANALYZED

Because the no-dig threshold was specified incorrectly based on geologic response masking the response from seed items, it is apparent that more targets should have been classified as "can't analyze" due to significant geologic response. However, there does not appear to be a suitable method for determining which targets originally classified as due to geology should be re-classified as "can't analyze". Because the correct number of "can't analyze" targets is indeterminable, a specific percentage has not been calculated. Were all of the targets currently classified as geologic response converted to "can't analyze", the percentage of "can't analyze" targets would be significantly higher than the acceptable rate of 5%.

7.11 CORRECT ESTIMATION OF TARGET PARAMETERS

Because some seeds were incorrectly identified as non-TOI, and in some cases were classified as geologic response, the target parameters (i.e., locations) for the sources were also incorrect. Because use of the MetalMapper for classification at the former WMA did not allow for classification of all TOI, its use on future projects is not recommended. Therefore, offset data were not calculated for sources that were identified as metallic sources.

8.0 COST ASSESSMENT

The cost assessment includes costs for project planning (demonstration plan and health and safety plan), site preparation (archaeological and biological surveys, surface sweep, and blind seeding, EM61 transect surveys, EM61 detection surveys, military munitions cued data collection and analysis costs, and intrusive costs.

8.1 COST MODEL

The cost model for the Waikoloa demonstration includes the total cost of the project. The total cost includes the seeding operation, MetalMapper operations, processing, and intrusive operation. Estimates for each operation are listed in Table 8-1.

Table 8-1: Details of Costs Tracked

Cost Element	Data Tracked During Demonstration	Estimated Costs
Project Planning	Demonstration Plan Health and Safety Plan	$25,400
Site Preparation	Archaeological survey Biological survey Surface sweep Blind seeding	$45,100
EM61 Survey	EM61 transect surveys EM61 detection surveys (5 acres)	$55,700
Military Munitions Data Collection	Cued data collection for 1,288 points over 1,032 anomalies Per target	$76,100 $74
Intrusive Investigations	All costs related to the intrusive investigation (1,880 results for 1,032 anomalies based on multiple items recovered from anomaly locations) Cost per anomaly to intrusively investigate	$220,000 $213

9.0 IMPLEMENTATION ISSUES

There were a few notable implementation issues regarding the Waikoloa project:

- The largest implementation issue was a GPS datum discrepancy at TO20B. All previous projects have used the UTM NAD 83 datum (United States specific) for dynamic data collection as opposed to the other possibility, the UTM WGS84 datum (world-wide). The MetalMapper collection software assumes the WGS84 datum, which created an approximately 75-cm difference between the detection data target locations shown on the screen and the actual source locations in the field. The MetalMapper collection team generally started trying to relocate selected targets at the anticipated location to the southwest of the point shown on the screen, but it was not a perfect solution. To ensure that all detected targets were excavated as intended, Parsons implemented the intrusive process detailed in Section 5.6, which considered both the dynamic target location and the MetalMapper data collection point. All dig list decisions were judged according to the source recovered at the MetalMapper collection point.
- Data collection went reasonably smoothly, but a great deal of effort needed to be placed on identifying sites suitable for traverse by the forklift used to transport the MetalMapper. There were very few locations within the project boundaries that were flat enough and that contained few enough jagged lava rocks for the MetalMapper to be used efficiently. Even if the TOI detection results had been more promising, the use of the MetalMapper at sites similar to those chosen for the project would have been extremely limited by terrain.
- In addition to the issues noted above with regard to transporting the MetalMapper across the data collection areas, it was fairly difficult just getting the field team out to the collection areas in TO20. At least a day was lost during data collection due to truck tires flattened during the drive out to the site. Replacing the standard tires on the rental trucks used for the project with larger, reinforced tires was successful in eliminating further delays but was not anticipated at the beginning of the project.

APPENDIX A
Black Tusk Geophysics
Processing of Geonics EM61 and MetalMapper Data
at the Former Waikoloa Maneuver Area

BTG Processing of Geonics EM61 and MetalMapper Data at the Former Waikoloa Maneuver Area

Introduction

Advanced EMI data were collected on the Former Waikoloa Maneuver Area at three sites: Task Order (TO) 17, TO20 Area A and TO20 Area B (Figure 1). Geonics EM61 data were acquired over each site (Figures 2-4) and anomalies were flagged for further investigation from the resulting data map. Cued interrogation data were subsequently acquired with the MetalMapper at each of the flagged anomalies.

GPS issues resulted in difficulties with the resulting survey data. At TO20 Area A, the GPS base station was configured assuming the NAD83 datum. However, the MetalMapper GPS unit assumed the WGS84 datum. This inconsistency produced a systematic shift between EM61 anomaly flag locations and the locations at which the MetalMapper visited. Partway through the data collection effort, this shift was recognized by the MetalMapper data collection team. The data acquisition team attempted to compensate for the shift by repositioning the MetalMapper towards the Southwest at each anomaly.

The significant background soil response at Waikoloa presented additional challenges for target picking and classification.The magnetic geology produces a large amplitude background instrument response that varies spatially across the site. The spatially varying geology and ground clearance variations due to cart movement can produce data anomalies that exceed the target picking threshold. In addition to difficulties with target picking, the background soil response can bias estimated target parameters when inverting data. Therefore, special care is required when removing or accounting for the magnetic soil background response.

There were two main objectives. The first was to develop a strategy for defining dig locations for the dig or interrogation teams. A successful approach would (1) overcome the systematic shift between EM61 anomaly locations and the locations visited by the MetalMapper, and (2) avoid unnecessary digs due to spurious anomaly picks due to magnetic geology. An approach was adopted that involved identifying anomalies where Geonics EM61 picks and MetalMapper source locations are far enough far apart such that both locations need to be interrogated (i.e. swept by the dig team with a handheld Minelabs sensor, and dug, if metal is determined to be present). For anomalies where MetalMapper location and EM61 flag are within 0.5 m, then it is only necessary to dig at the EM61 flag.

The second objective was to determine if it is possible to accurately estimate dipole source parameters for targets buried in the highly magnetic geology of Waikoloa. The standard survey approach is to collect background measurements at locations close to an anomaly, and then to subtract the background measurement from the anomaly data. This “background corrected” data can then be inverted using the simplified model of a target in free-space. Unfortunately, there were an insufficient

number of background soundings to reliably background correct the data. In addition, the spatial variability of the background geology, strength of the magnetic field, and the effect of inconsistent ground clearance height between anomaly data collection and background measurements can produce inaccurate estimates of the background response. We adopted an approach where the background response was estimated as part of a constrained inversion process. More specifically, a deep dipole source was used to model the effect of magnetic soil.

This document outlines the dig location strategy and the inversion approach. Our work was completed as part of ESTCP MR-201226 and SERDP MR-2318.

Determining if a target is a soil anomaly

Electromagnetic induction instruments are sensitive to ferri-magnetic minerals such as magnetite. When these minerals are exposed to a magnetic field, there is a non-instantaneous change in magnetization. Pulse induction instruments such as the MetalMapper, TEMTADS and MPV measure the secondary field in the off time produced by the magnetic grains as the aligned magnetization relaxes to a more random state. The secondary field amplitude is a function of the concentration of ferri-magnetic minerals in the soil, the distribution of time constants characterizing the relaxation times, and the geometry between the transmitters, receivers, and ground. The factors that determine the strength of the magnetic soil response are outlined in detail in the final reports for SERDP projects MM-1414 and MM-1573.

The Geonics EM61 was used to map the Waikoloa sites. The EM61 has a coaxial transmitter/receiver geometry that produces the maximum coupling to magnetic soil. As a result, we can use the EM61 data to map the approximate variability in magnetic soil response. Since the EM61 survey did not have "in-air" measurements to establish an absolute zero level, a DC shift was estimated for each data segment such that the shift between adjacent data segments were minimized when assembling the data map. Figure 5-8 compares the along line, median filtered data provided by Parsons to data re-leveled to show how the background response varies across the three areas. The third time channel is gridded to form the image. In both the median filtered data and the data leveled to show geology, there is a short wavelength, along-line oscillation of the data related to the bouncing of the EM61 cart producing a periodic change in ground clearance height. The regions of negative values in the median filtered data image are due to filtering artifacts. TO17 has the highest level of the magnetic geology noise with magnetic soil responses exceeding 35 mV in the 3rd time channel (Figure 8). The median filter was not able to remove the linear geologic features in the data. Distinct anomalies related to targets are not easily identified in the data, and numerous soil related anomalies picked for interrogation would be expected.

In order to identify cases where the MetalMapper measured data over a magnetic geology anomaly instead of a metallic target, we compare the MetalMapper data with a soil model. Background measurements were used to determine the MetalMapper's characteristic magnetic soil response. Figure 16 plots the background response for five of the background measurements. Receiver Rx0 was not working properly during these measurements. The measurements were corrected using in-air

measurements. When the MetalMapper is parallel to flat ground, we would expect that the coaxial component of the secondary response measured by the center receiver (Rx3) would be at a maximum. Conversely, the transverse components would be null-coupled. For example, the X and Y-component receivers should measure only noise when the Z-component transmitter is firing. When the instrument is not parallel to the ground surface, there will be some signal in these transmit/receive pairs.

The first step to building a soil model was to use the decays measured by the MetalMapper to determine how the MetalMapper transmitter waveform modified the characteristic 1/t decay of the magnetic soil. The decay characteristic is independent of the ground clearance height and orientation of the sensor relative to the soil surface. The consistent decay character for the different Tx/Rx combinations can be seen in Figure 16. The decay character is well modeled by the function:

$$f(t) = \frac{1}{t} - \frac{1}{t + \Delta t}$$

This function is the characteristic 1/t VRM response convolved with a finite pulse transmitter waveform.

If we assume that the ground clearance height and sensor orientation is approximately constant over the course of the survey, then the relative strength of the magnetic soil response between each Tx/Rx combination can be assumed to be constant during the survey. The background measurements suggested that the variations in the relative amplitude of soil responses between each Tx/Rx combination were not significant. Therefore it is reasonable to construct a soil model consisting of the decay character f(t) which multiplies an amplitude for each Tx/Rx combination. This result simplifies the soil fitting analysis. Instead of requiring potentially inaccurate estimates of ground clearance height and sensor orientation to model the background response, we can simply estimate a single scaling parameter that multiplies our soil model. If the ground clearance and sensor orientation is constant during the survey, the value of the single scaling parameter provides a measure of the soil magnetic susceptibility.

For each MetalMapper measurement, the soil model is fit to the measured data. The misfit between the best fit soil model and data reflects the likelihood that the measurement was acquired in the presence of a metallic target. Figure 17 has an example of soil model fitting using data over Target 785 on the Western edge of the TO17 area. The absolute value of the observed data is plotted as blue circles, with a solid blue circle indicating positive data and unfilled (i.e. white) circles with a blue outline indicating negative data. A black dashed line indicates the best fit soil model. There is a very good match between the observed data and the soil model. For the null-coupled Tx/Rx combinations, the soil model predicts some signal. This is consistent with analysis of the background data files and suggests that the MetalMapper was consistently slightly tilted when acquiring the cued data. When reviewing inversion results, the analyst is provided a soil misfit to assist in determining if the data anomaly is due to soil.

Selecting Dig locations

Due to an inconsistency in the datum assumed for the GPS rover and base station, there were systematic errors in MetalMapper positioning when data were collected in TO20 Area B. Figure 10 to Figure 12 compares the locations at which the MetalMapper data were collected to the locations of targets picks from the Geonics EM61 data.

Figure 10 summarizes location errors for TO17. Approximately 90% of MetalMapper anomalies were collected within 50 cm of the EM61 flag (black triangle and '+' symbols). There is an additional peak in the histogram at approximately 0.5 m. This peak is related to the survey methodology - during recollects of a sounding, the field crew would not acquire additional soundings at locations greater than approximately 0.5 m from the original anomaly flag. The differences between MetalMapper sounding locations and EM61 target picks were similar in TO20 Area A (Figure 11). Approximately 85% of MetalMapper anomalies were acquired within 50 cm of the EM61 flag, and there was again a peak at approximately 0.5 m from the original anomaly flag. Figure 12 summarizes the differences for TO20 Area B. Less than 62% of the anomalies had data acquired within 0.5 m of the EM61 pick. Figure 13 shows the consistent South-west bias between the MetalMapper locations on top of the EM61 data for TO20 Area B.

A decision logic for choosing dig coordinates was established during a meeting with members from Parsons, Black Tusk Geophysics, the ESTCP program office, and the USACE. Figure 14 summarizes the decision logic for choosing target dig coordinates. In TO20 Area B, inaccurate flag locations were given to the MetalMapper data collection team. Therefore, all EM61 flag locations in TO20 Area B would be investigated, and all MetalMapper source locations that measured non-soil like data would also be investigated. For TO20 Area A and TO17, it is not necessary to investigate every EM61 flag. For cases where the MetalMapper location and EM61 flag are greater than 0.5 m apart, and analysis of the MetalMapper data suggests a non-soil target, the dig team will only have to investigate at the location of the MetalMapper source and not at the EM61 flag.

Inversion of MetalMapper data at Waikoloa

The standard procedure when collecting cued EMI data is to take background measurements. These background measurements are then subtracted from data acquired over targets. These "background corrected" data can be modeled as a dipole in free-space. This approach requires a background measurement acquired close enough to each anomaly such that there is an accurate estimate of the background signal for each anomaly. At sites with large magnetic soil response, this approach can have limited success. This is because small changes in ground clearance and changes in orientation of the MetalMapper can result in a significant change in amplitude of the soil response. A change in ground clearance of only a few centimeters can result in a change of background response of several tens of percent (SERDP MR-1573 Final Report). Overestimating or underestimating the background response will reduce the accuracy with which the dipole polarizabilities are estimated as shown in Figure 15 for TEMTADS 2x2 data collected at Waikoloa.

An alternative to subtracting a background measurement prior to the inverting the data is to solve for the soil response as part of the data inversion. Several modeling based approaches were considered in SERDP 1573. It was noted in SERDP 1573 that, for cued MetalMapper data, the magnetic soil response could be modeled well with a deep dipole source. For the Waikoloa cued MetalMapper data, we developed a multi-dipole source inversion, where the location of a deep source is fixed beneath the center of the array. This single deep source will model the background response due to soil, and the remaining sources will model any buried metallic targets.

Figure 17 contains a typical result when fitting cued MetalMapper data taken over a soil anomaly with a dipole source. Three lines are shown on each plot: observed data are plotted in blue, the best fit soil model is plotted in black, and the predicted data when using a single source inversion is plotted in green. The observed data is fit well with both the best fit soil model and the single deep source. The recovered dipole polarizabilities and relative depths when inverting for 1, 2, and 3 sources are shown in Figure 18. The single source inversion shows that the soil can be fit with a plate-like target oriented with the normal of the plate parallel to the horizontal direction. Solving for two dipole sources results in a deep plate-like target, and a shallow small amplitude target that fits noise. Three sources adds a second small amplitude target at the surface. To represent the soil response, we choose to use the simpler model of a single deep source. Analysis of background measurements corrected with an in-air sounding were used to determine that a source depth of 95 cm would model the soil response well. Figure 19 shows that there is a second local minimum in the fitting problem where the soil is fit well with two sources: one source at 40 cm and a second source at approximately 95 cm.

IVS data were used to test the deep-source soil modeling methodology. The IVS contains 3 targets. Targets 1 and 3 are the same 37 mm. Targets 1 and 2 are horizontal and buried such that the geometric center of the target is at a depth of 10 cm. Target 3 is vertical, with the geometric center of the target being at 12 cm. The IVS data were inverted using in-air measurements for background correction, and the data were fit using (a) single source inversions, (b) two source inversions in which the location of both sources were unconstrained, and (c) two source inversions in which the location of one of the sources was constrained to be deep and centered on the MetalMapper instrument. Figure 20 compares the recovered polarizabilities from the three types of inversions. When inverting for a single source, the amplitudes of the polarizabilities are overestimated since the source is trying to fit both the 37 mm projectile and the soil response simultaneously. Inverting for a pair of sources improves the amplitude of the polarizability estimates. Inverting for a pair of sources, with one source fixed deep to represent the background soil response produces similar results to the unconstrained two source response for IVS target 1 and IVS target 2, with only marginal improvements in the spread of recovered polarizabilities. There is a more pronounced improvement when fitting IVS Target 3, with a larger spread in recovered polarizabilities when inverting for two unconstrained sources. Fitting IVS target 3 with a deep source improves the accuracy of the recovered polarizabilities.

Figure 21 compares the size vs. decay feature plot for the IVS inversions. Figure 21(a) shows that, when inverting the data with only a single source inversion, there is a bias in the recovered feature clusters since the polarizability size is overestimated and the estimated decay rate slower than expected due to the dipole source trying to fit both the target response and soil. When inverting the data with two

unconstrained sources, the second source models the response of the ground, and the bias seen in (a) is removed (Figure 21(b)). The size and decay features associated with the source that models the soil is outlined with a black dashed line. Figure 21(c) shows that the feature clusters are better constrained for the IVS targets when the second source is constrained to be deep and centered at the center of the anomaly. In addition, using the constrained inversion results in the size and decay characteristics of the soil sources being constrained better than in (b).

We processed the Waikoloa MetalMapper cued data using both the soil modeling method described above, and also using the standard background correction method using available background measurements. One, two, and three source inversions for the two background correction methods resulted in 12 models for each anomaly. From these set of models, the coordinates of any models characteristic of a compact metallic target was recorded as a potential location for a dig team to visit.

Deliverables

PDF files were generated that summarized analysis for each MetalMapper measurement. Each page of the PDF files contains the following information for an anomaly:

- The MetalMapper CSV file name, MetalMapper target location, EM61 flag location, soil model misfit, distance between EM61 flag location and MetalMapper source location
- The dig logic is summarized in magenta. The soil model misfit is reported.
- A small chip of EM61 data (as filtered by Parsons) is plotted with the MetalMapper source location and EM61 flag location plotted on top. The first time channel of EM61 data is plotted
- The location of the anomaly is plotted on a map of the EM61 map of the entire grid.
- The data fit is shown for each transmitter/receiver combination. The best fit soil model is shown with black dashed lines.
- For anomalies that were not classified as soil models, the recovered polarizabilities are plotted in the upper right of the page.

Figure 22 to Figure 24 include examples of the PDF summaries for three anomalies in TO20 Area B. The information contained in the PDFs was also provided in a number of Excel spreadsheets. An example of the Excel spreadsheets can be found in Figure 25.

In addition to the MetalMapper analysis, additional dig locations based on MPV data were provided. A summary of that process is provided in the report for ESTCP MR-201158.

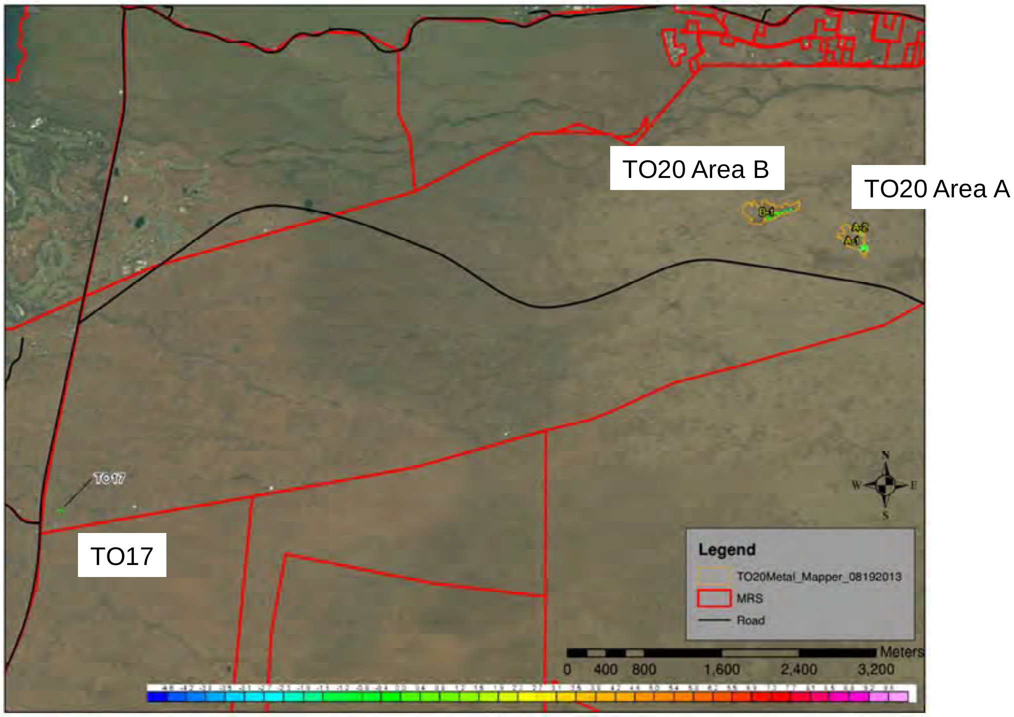


Figure 1: Site Area. Three survey areas were analyzed: TO17, TO20 A and TO20 B.

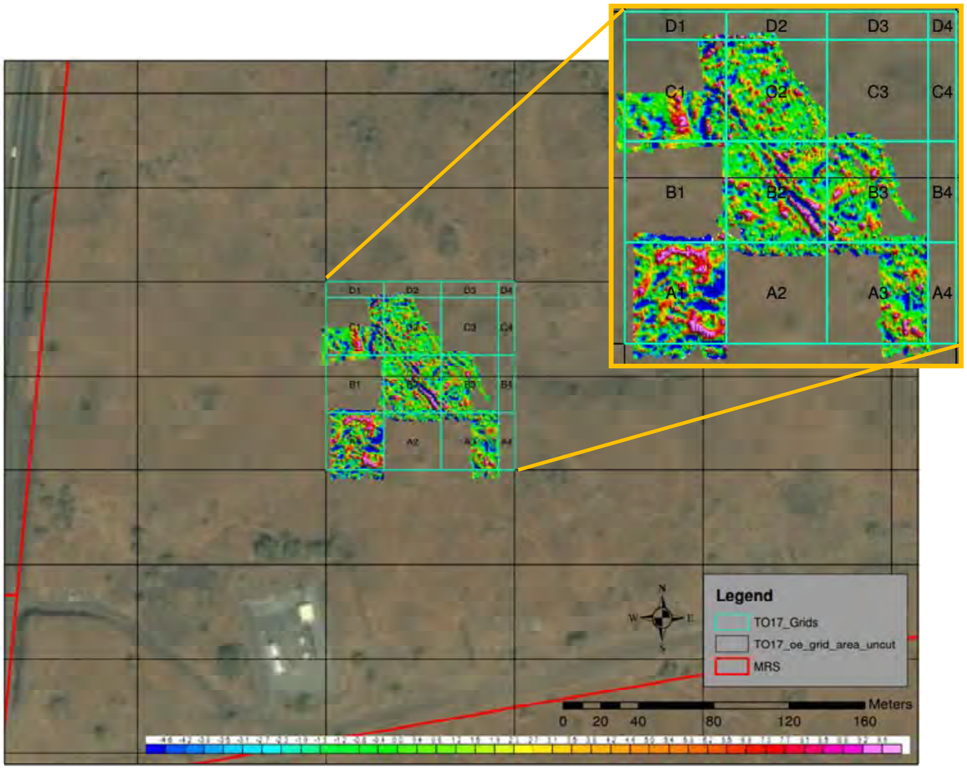


Figure 2: Area TO17. Geonics EM61 data acquired and median filtered by Parsons are overlaid on the grid area.

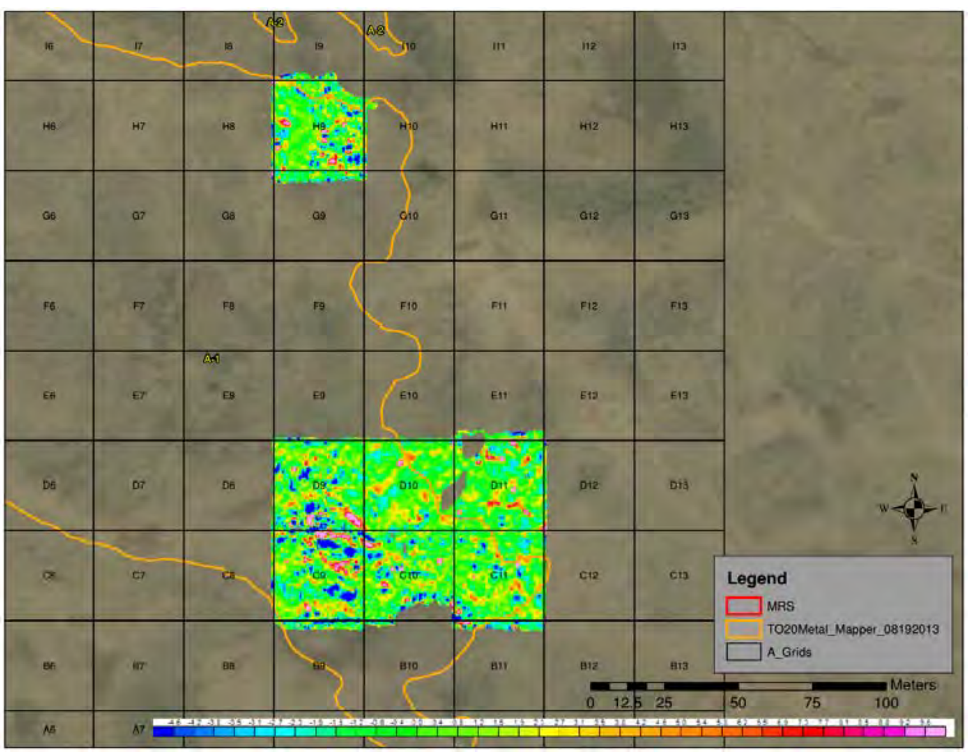


Figure 3: Area TO20A. Geonics EM61 data acquired and median filtered by Parsons are overlaid on the grid area.

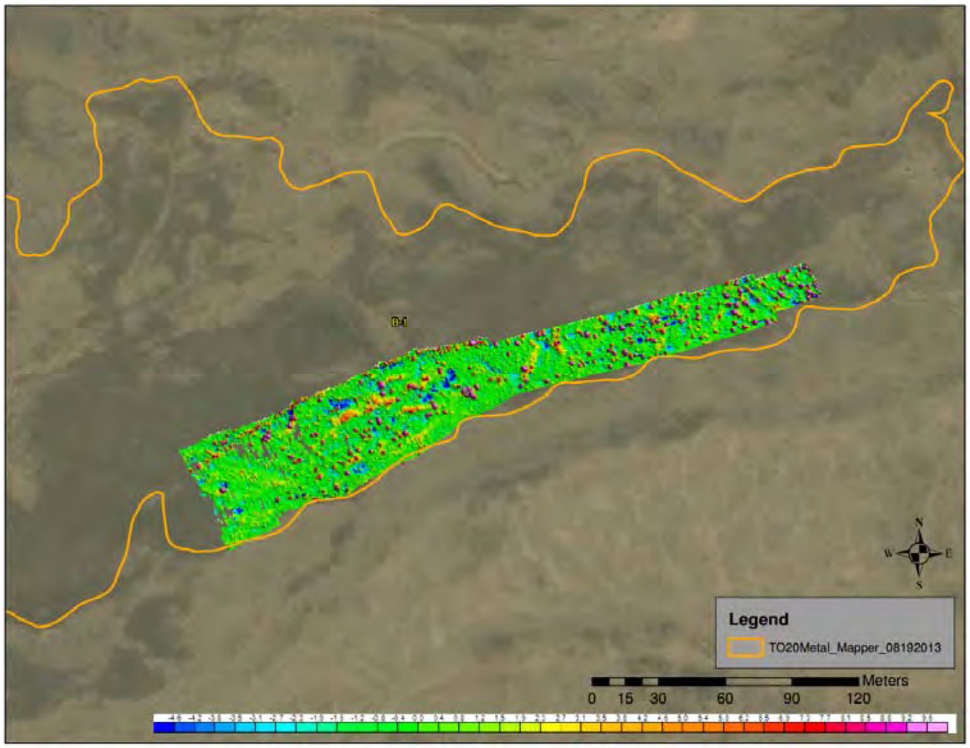


Figure 4: Area TO20B. Geonics EM61 data acquired and median filtered by Parsons are overlaid on the aerial map.

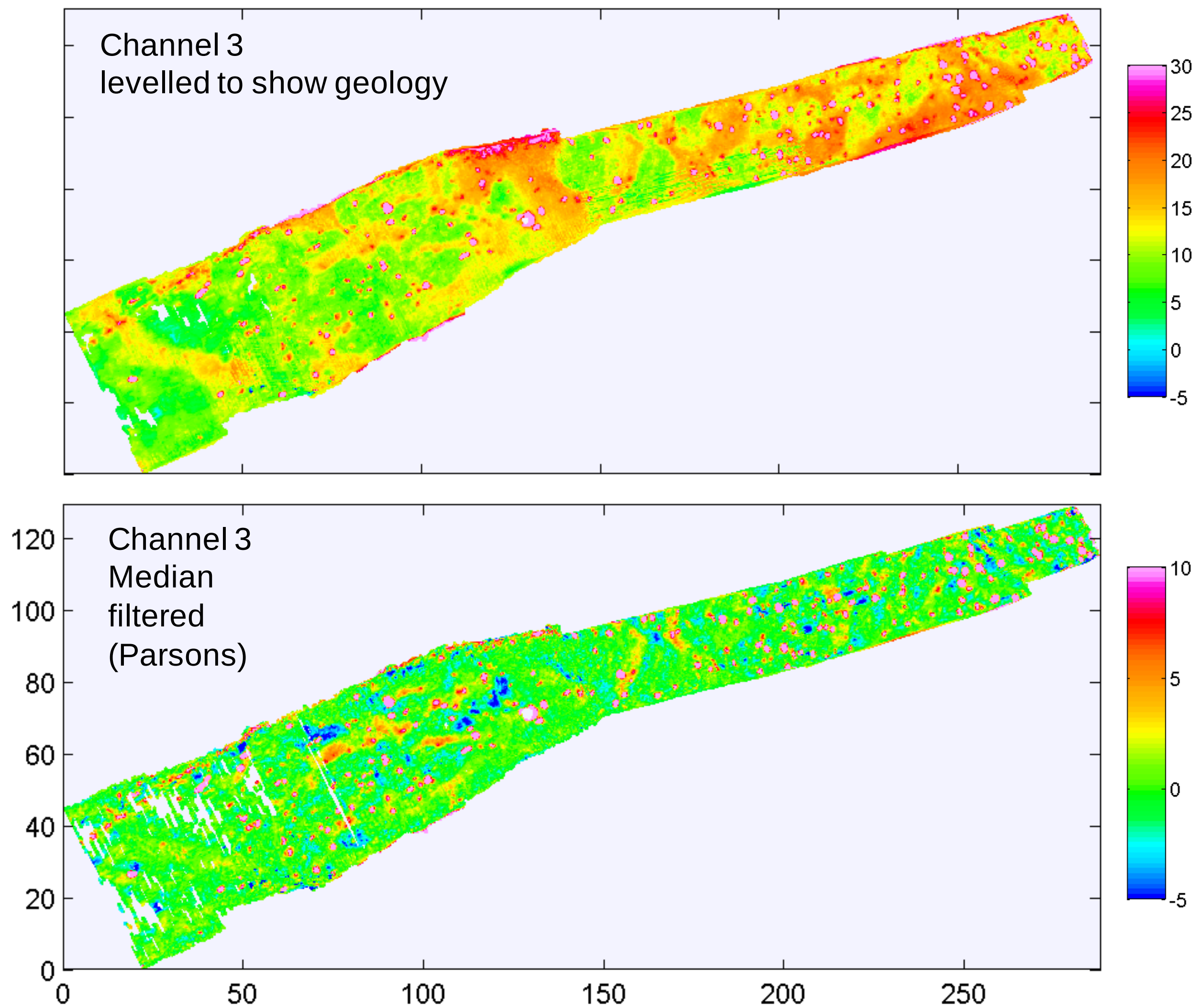


Figure 5: TO20 Area B. Data levelled to Show Geology.

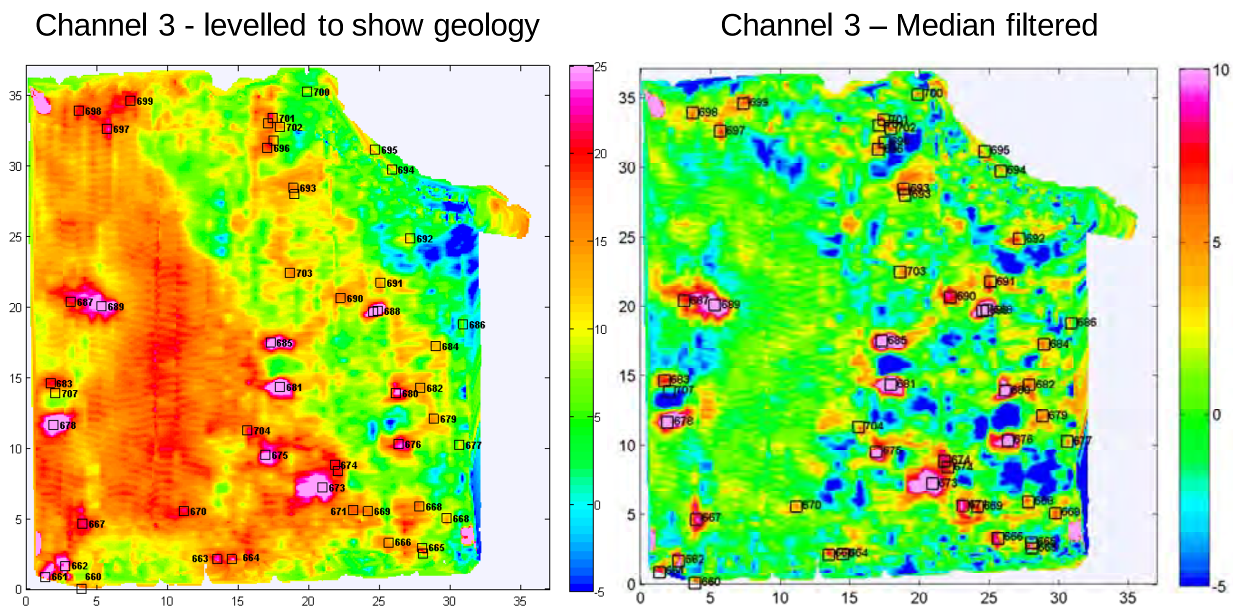


Figure 6: TO20 Area A, North. Data levelled to Show geology.

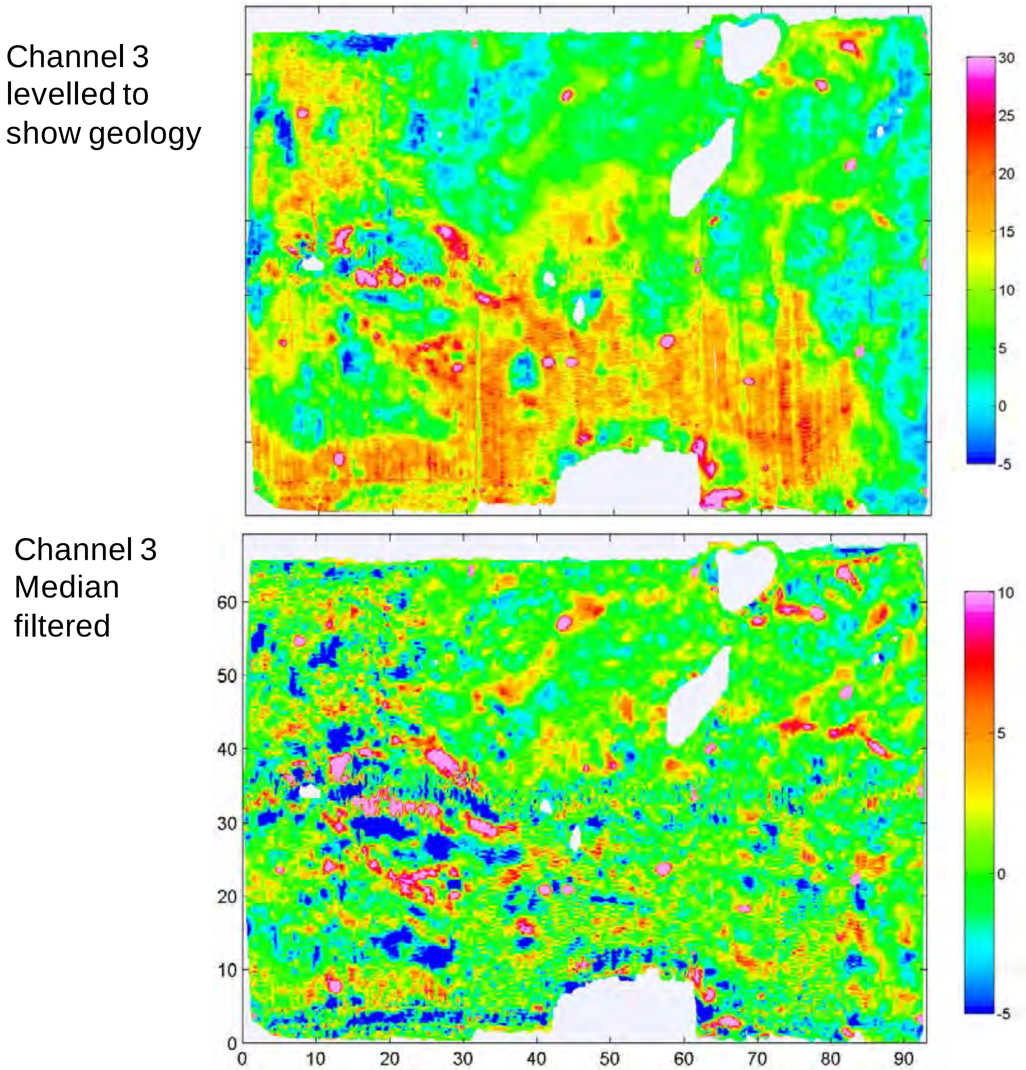


Figure 7: TO20 Area A South.

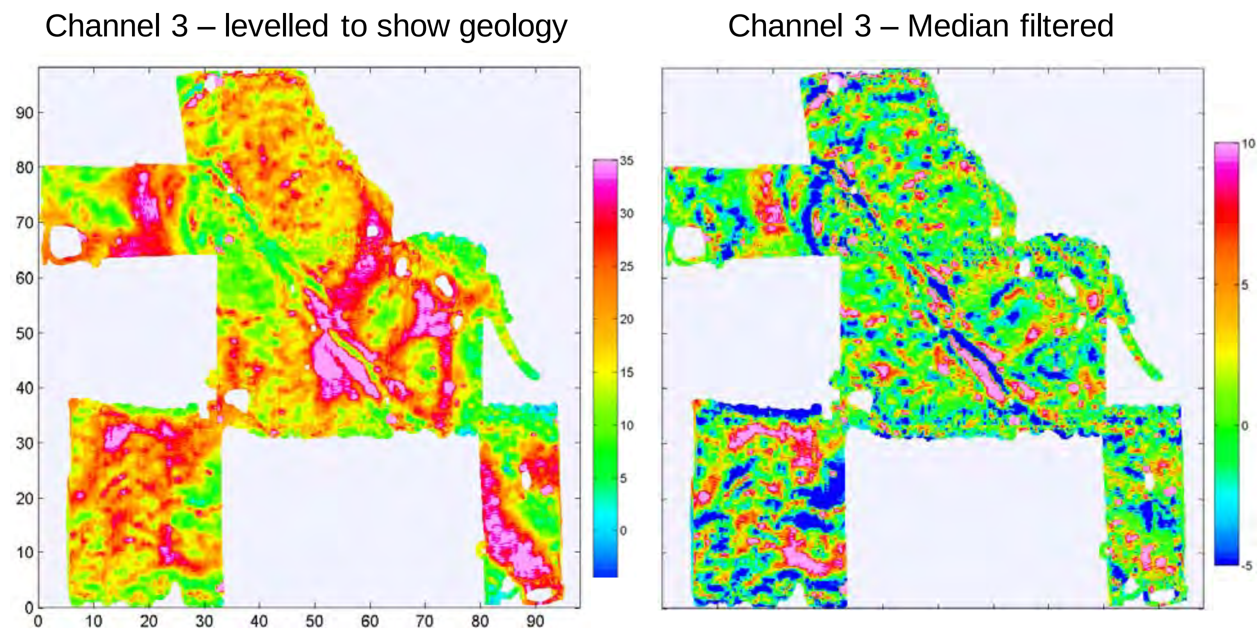
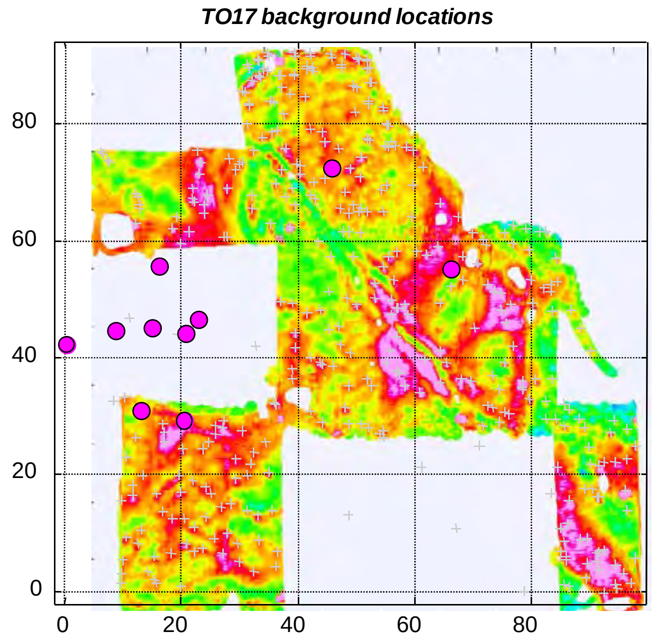
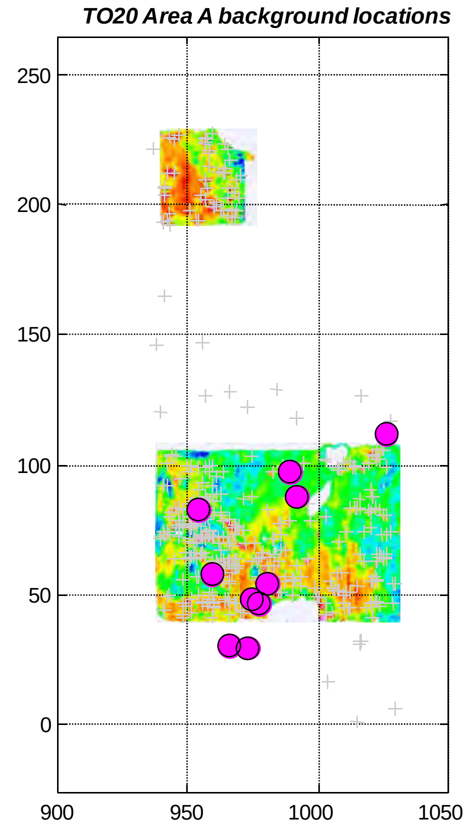


Figure 8: TO17. Data leveled to show geology.





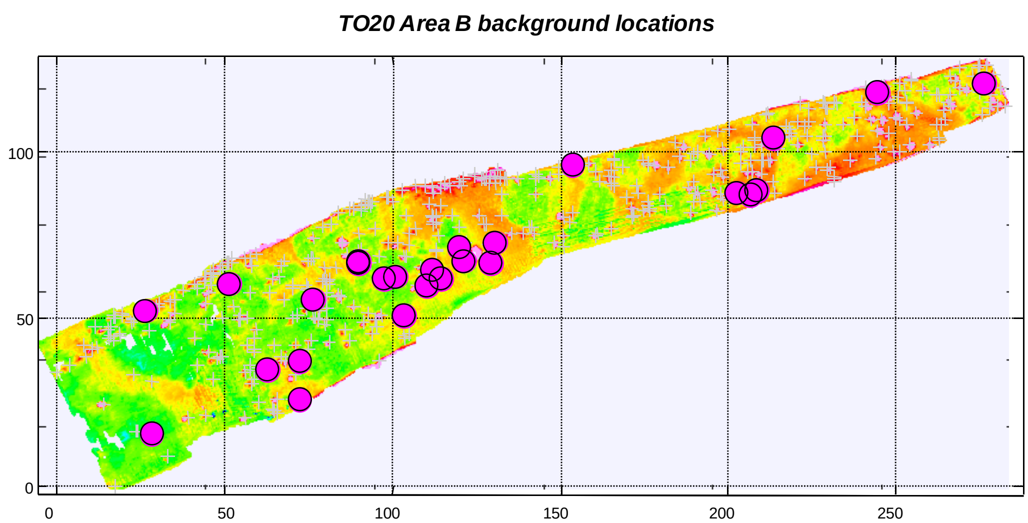
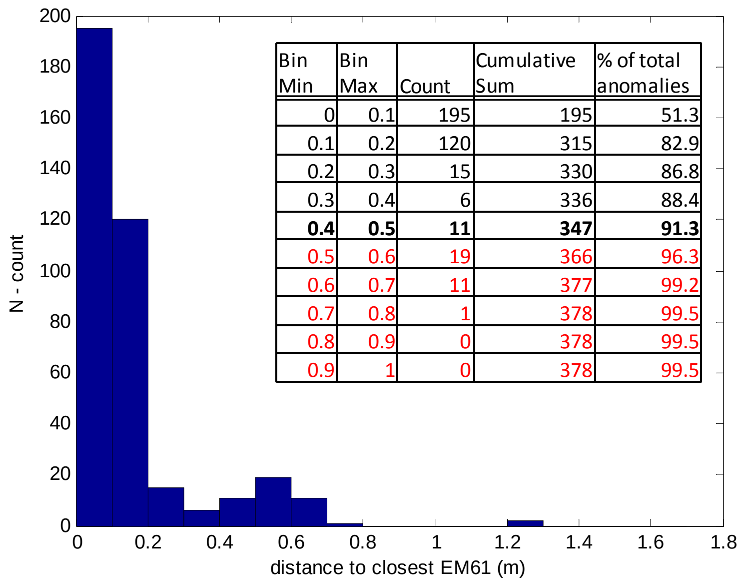


Figure 9: Location of background soundings. Magenta circles indicate locations at which background soundings were collected.



Bin Min	Bin Max	Count	Cumulative Sum	% of total anomalies
0	0.1	195	195	51.3
0.1	0.2	120	315	82.9
0.2	0.3	15	330	86.8
0.3	0.4	6	336	88.4
0.4	**0.5**	**11**	**347**	**91.3**
0.5	0.6	19	366	96.3
0.6	0.7	11	377	99.2
0.7	0.8	1	378	99.5
0.8	0.9	0	378	99.5
0.9	1	0	378	99.5

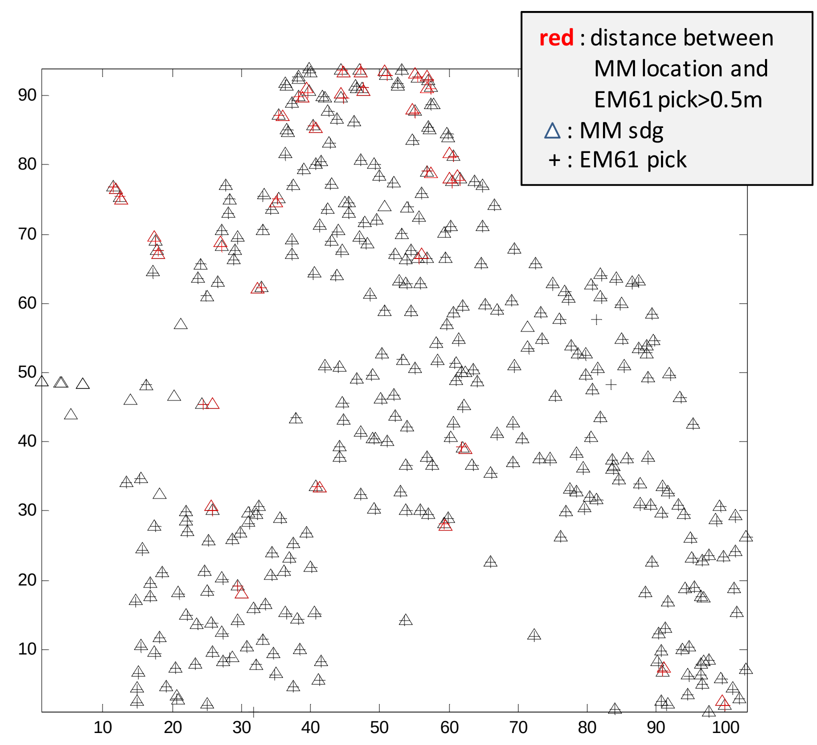
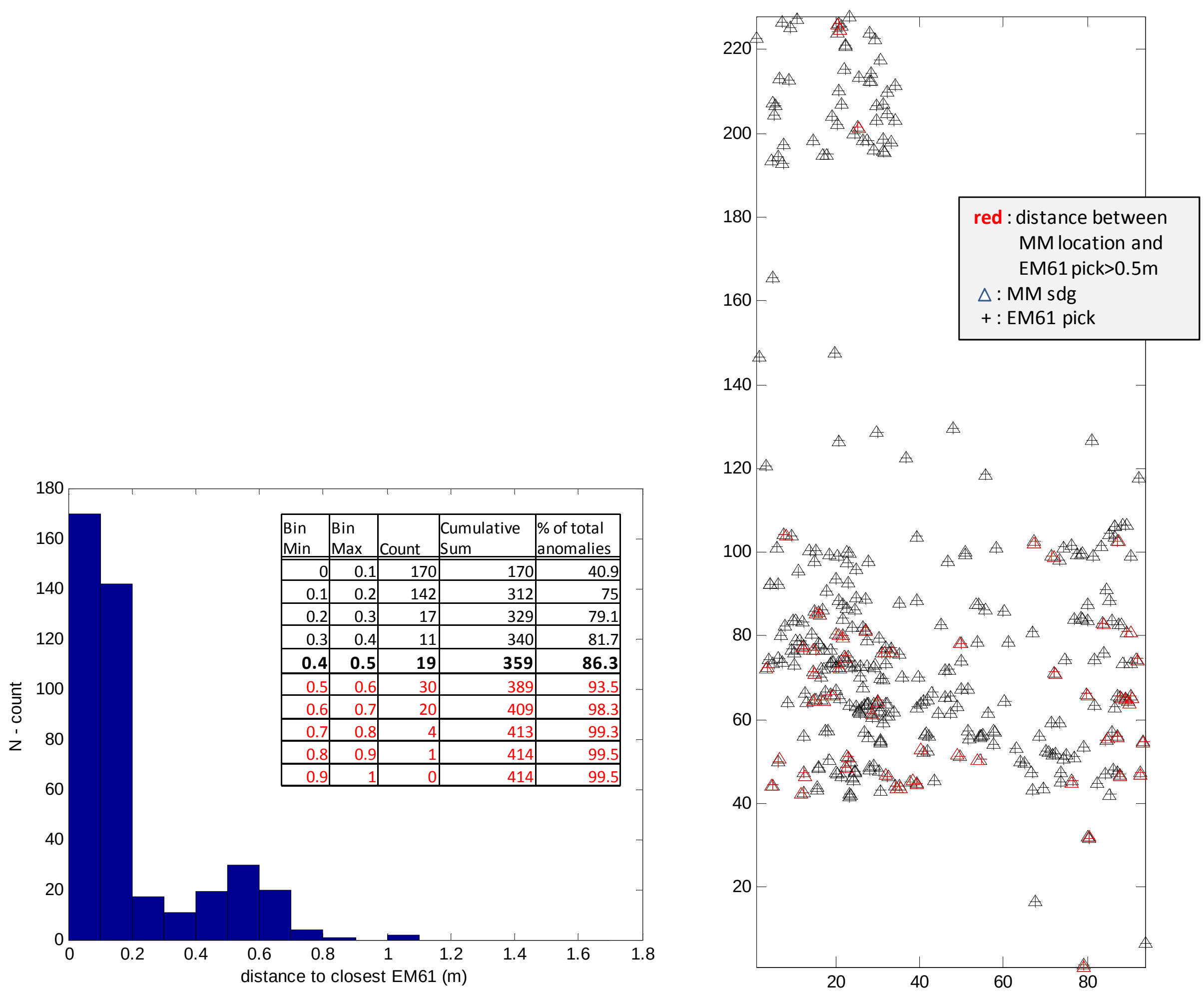
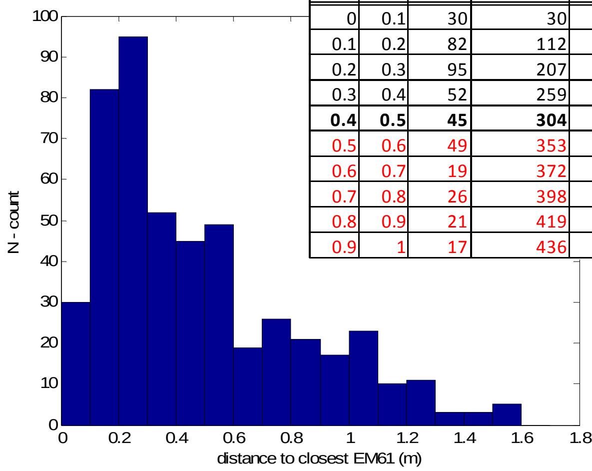


Figure 10: TO17. Comparison of EM61 pick location and MetalMapper sounding location



Bin Min	Bin Max	Count	Cumulative Sum	% of total anomalies
0	0.1	170	170	40.9
0.1	0.2	142	312	75
0.2	0.3	17	329	79.1
0.3	0.4	11	340	81.7
0.4	**0.5**	**19**	**359**	**86.3**
0.5	0.6	30	389	93.5
0.6	0.7	20	409	98.3
0.7	0.8	4	413	99.3
0.8	0.9	1	414	99.5
0.9	1	0	414	99.5

Figure 11.TO20 Area A.Comparison of EM61 pick location and MetalMapper sounding location



Bin Min	Bin Max	Count	Cumulative Sum	% of total anomalies
0	0.1	30	30	6.1
0.1	0.2	82	112	22.8
0.2	0.3	95	207	42.2
0.3	0.4	52	259	52.7
0.4	**0.5**	**45**	**304**	**61.9**
0.5	0.6	49	353	71.9
0.6	0.7	19	372	75.8
0.7	0.8	26	398	81.1
0.8	0.9	21	419	85.3
0.9	1	17	436	88.8

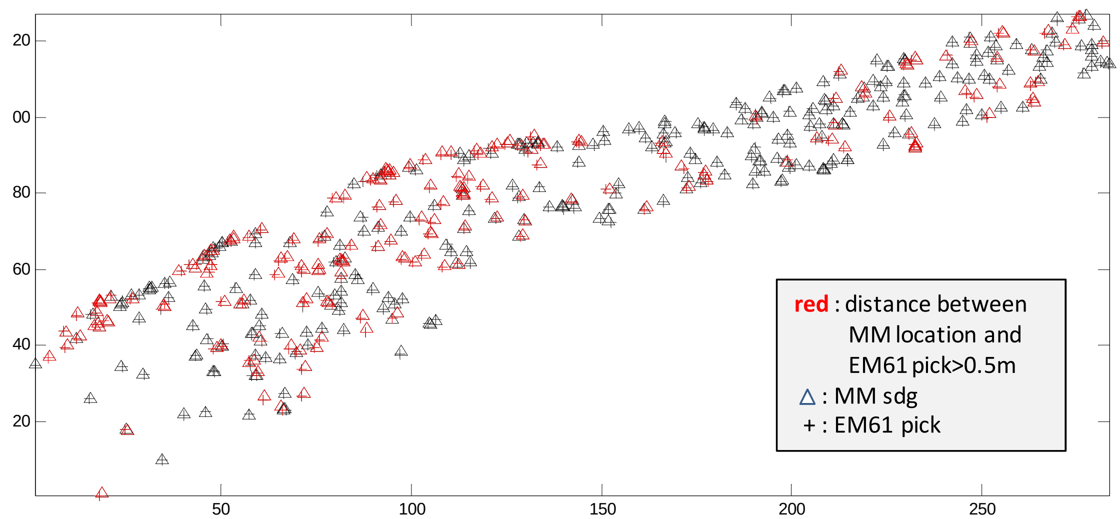


Figure 12: TO20 Area B. Comparison of EM61 pick locations and MetalMapper Sounding locations.

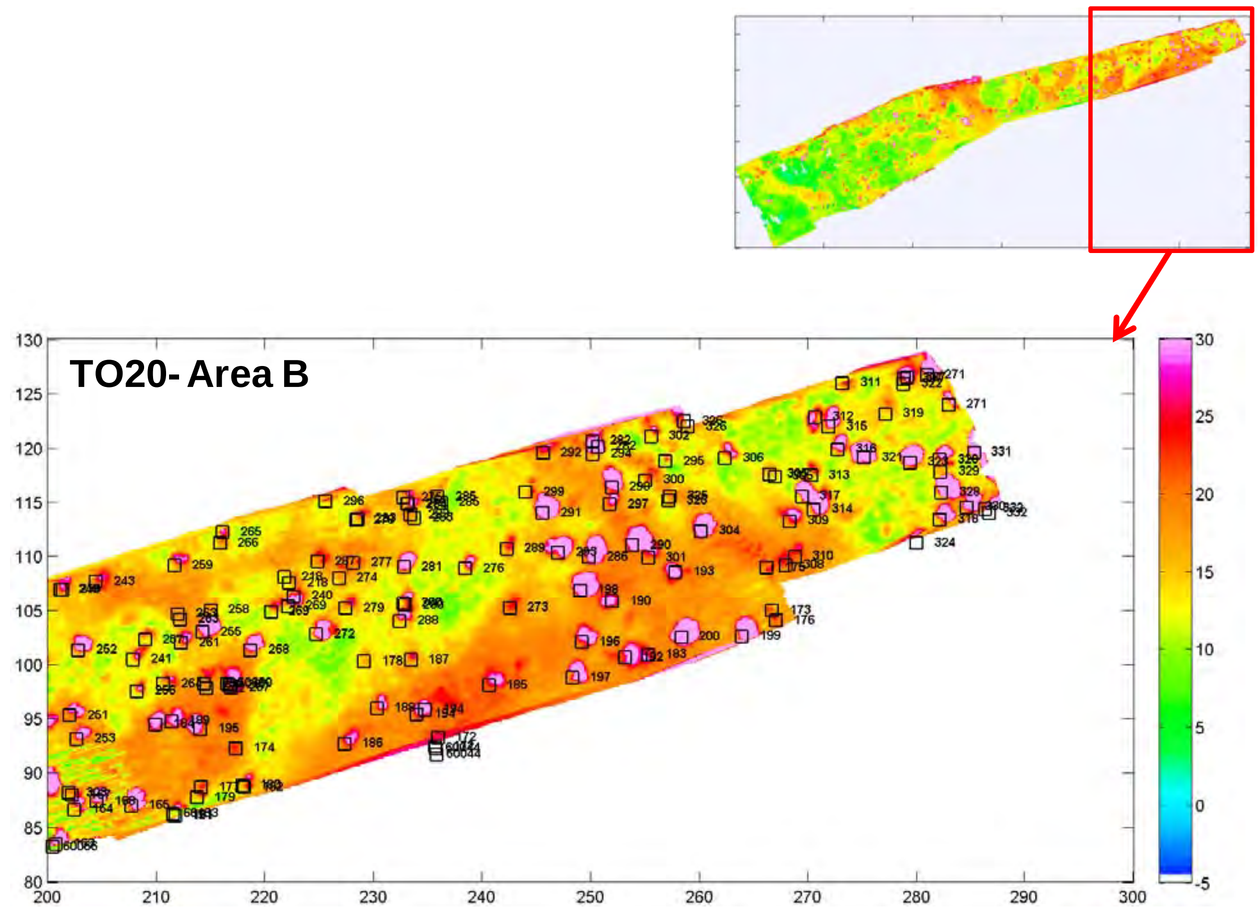
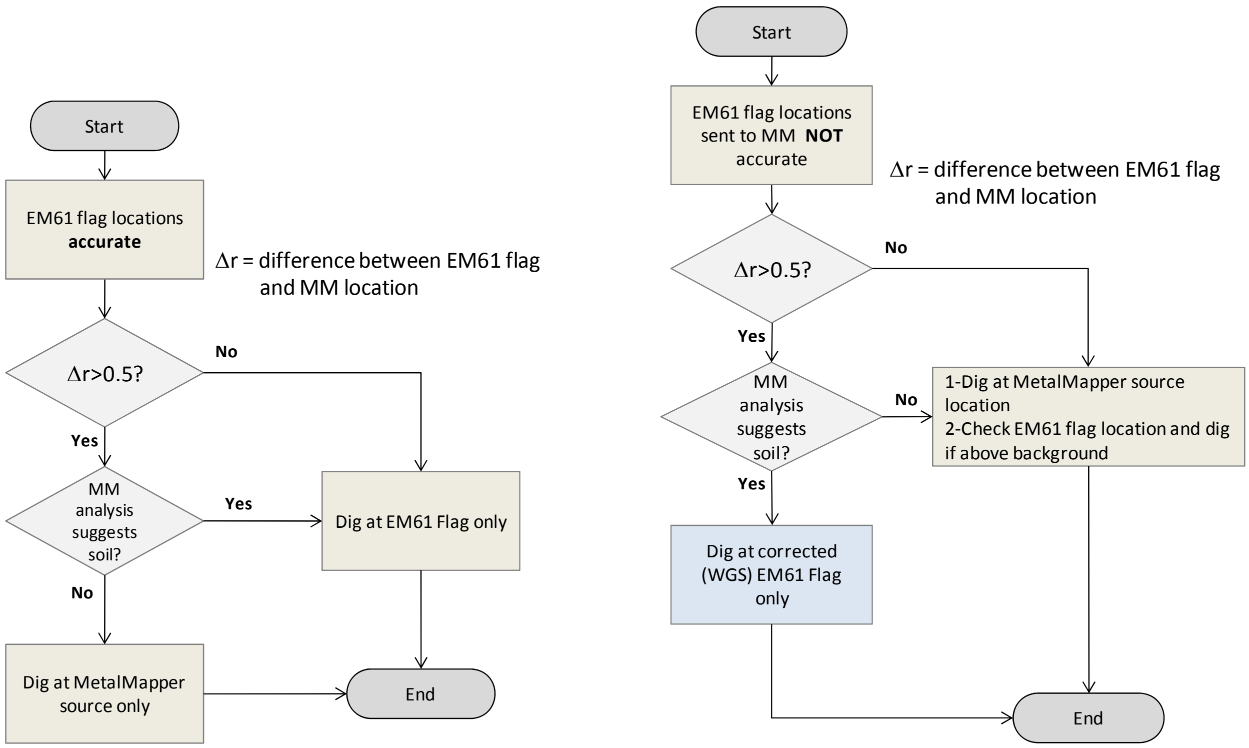


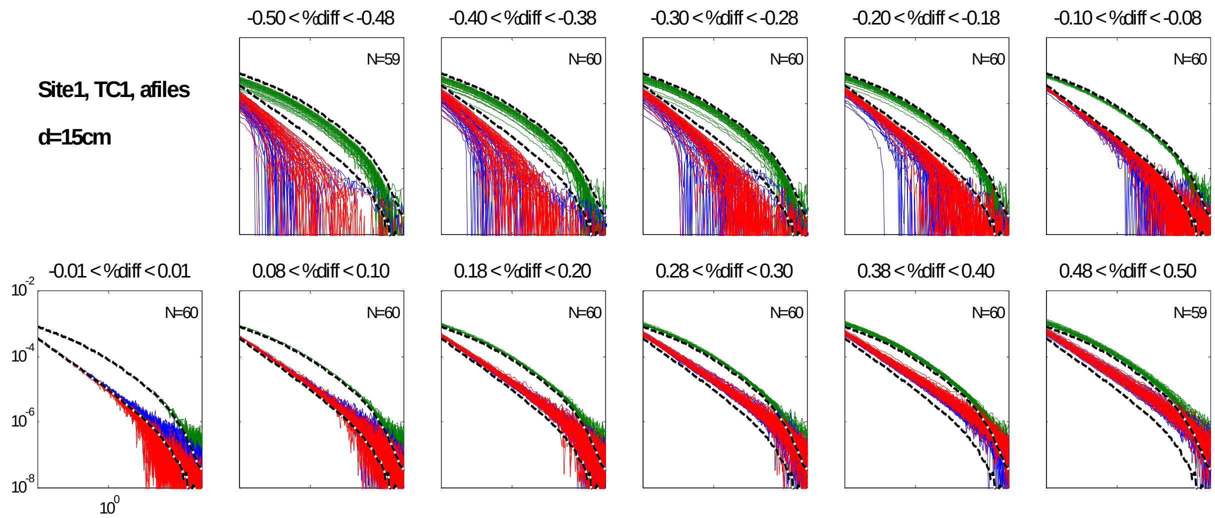
Figure 13: Close-up of east section of TO20-Area B. In this area there is a consistent Southwest bias between the EM61 data anomalies, and where the MetalMapper acquired cued data.



(a) TO20 Area A and TO17 (b) TO20 Area B

Figure 14: Decision logic for choosing target dig coordinates. In TO20 Area B, inaccurate flag locations were given to the MetalMapper data collection team. The approach outlined above represents a conservative approach: all EM61 flag locations would be investigated, and all MetalMapper source locations that measured non-soil like data would also be dug. For TO20 Area A and TO17, it is not necessary to dig every EM61 flag.

(a) ISO2 depth = 15 cm



(a) ISO2 depth = 30 cm

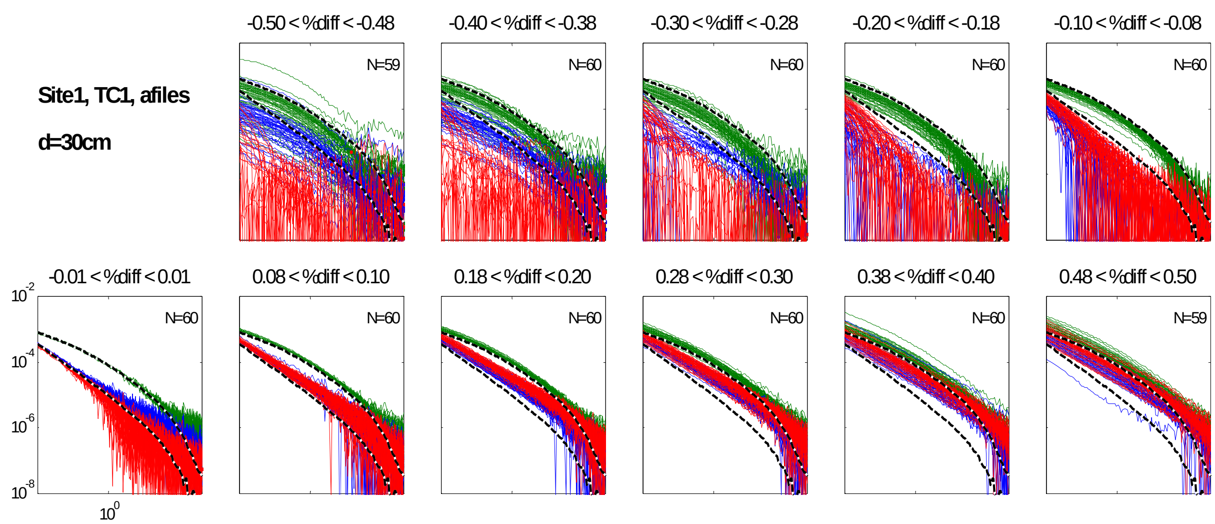


Figure 15: Comparison of recovered polarizabilities when inverting cued TEMTADS 2x2 data with inaccurate estimation of the background response. For this example, we use background soil responses measured with a TEMTADS 2x2 sensor on Waikoloa. Each panel overlays results from N simulations falling within the percent difference from the true polarizability range in the panel title. When the percent difference is less than 0, we are overestimating the background response. As a result, the polarizability amplitude is reduced, and there are poor estimates of the secondary polarizabilities. When the percent difference is greater than zero, the background response is underestimated, therefore leaving soil noise in the data to be inverted. For this case, the estimated polarizability is greater than the true polarizability, and the secondary polarizabilities follow the decay of the background soil. When the ISO2 is at a depth of 30 cm, these effects are more significant, and the ability to recover informative polarizabilities is more sensitive to errors in the background estimation.

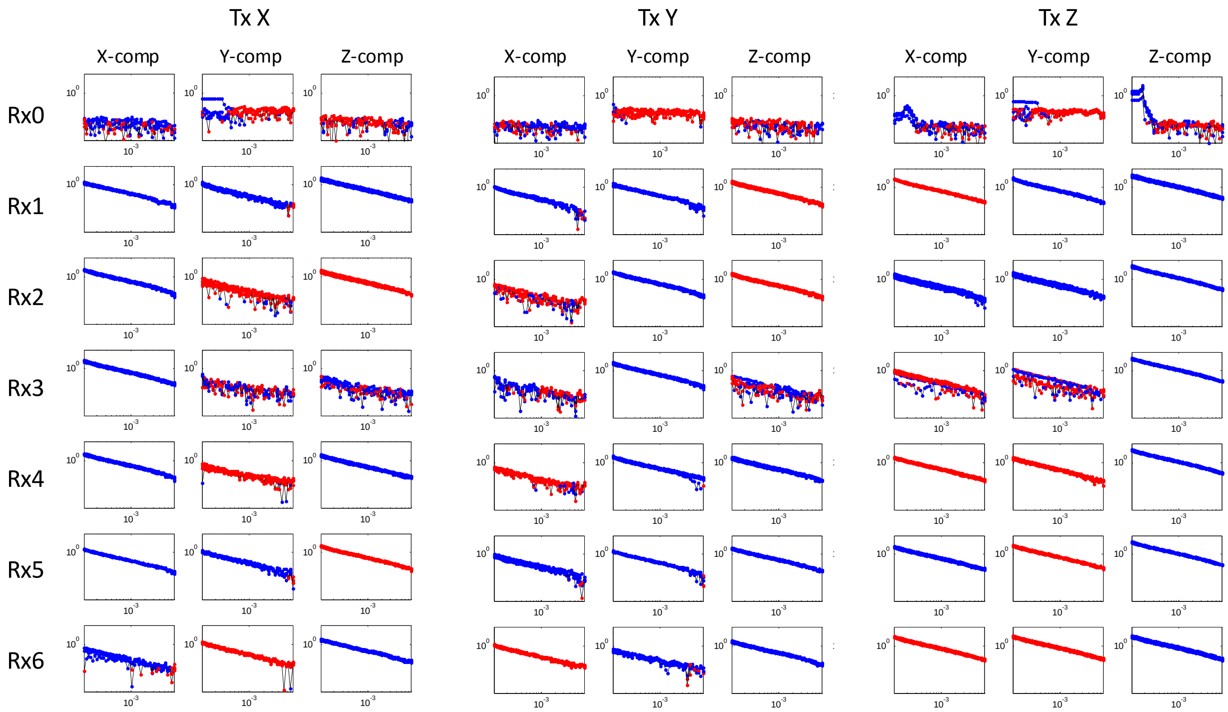


Figure 16: Example of background measurements corrected with air. Blue lines are for positive responses, and red lines represent negative responses. Receiver Rx0 was not working properly during these measurements.

APPENDIX B
Failure Analysis Memorandum

Failure Analysis Memo

Site: Waikoloa

Analyst: Black Tusk Geophysics

Data: MM Cued

Date: January 23, 2015

Our stage 1 dig list missed nine QC seeds (see table below).

Table 1: List of nine missed QC seeds. Last column is a classification based on data match to a soil model and visual inspection of observed data and predicted polarizabilities.

Dig number	Anomaly	Survey Area	Identification	Depth (cm)	Soil anomaly?
370	402	TO20-A	37mm (TP)	29	No
383	1026	TO17	60mm Mortar	34	Yes
396	715	TO20-A	37mm	25	No
427	203	TO20-B	60mm	40	Yes
528	391	TO20-B	60mm mortar	45	Yes
555	393	TO20-B	60mm mortar	45	Yes
568	707	TO20-A	37mm	20	Yes
660	474	TO20-A	60mm mortar	40	Yes
692	73	TO20-B	37mm TP	11	Yes

The missed QC seeds were distributed amongst all three areas. The stop dig point on our stage 1 dig list was dig number 295. The missed QC seeds occurred between digs number 370 to 692. (Total number of anomalies is 939.)

a. Analysis of the factors that resulted in the misclassification of each missed seed

For each anomaly of the Waikoloa MetalMapper Cued dataset we performed six inversions, comprising two sets of three inversions. In both sets we solved for (1) a single object (single object inversion: SOI); (2) two objects (2OI); and (3) three objects (3OI), resulting in six models per anomaly. In the first set of three inversions we used data that were background corrected using the nearest in-air background measurement. For the two- and three-object inversions, the location of one source was fixed at the center of the MetalMapper array at a depth of 90 cm. Previous investigations showed that the fixed source can be effective at representing the soil component of the signal. The single-object inversion in this set will typically be unreliable because not enough background will have been removed.

In the second set of three inversions we used data that were corrected using the nearest normal (close to the ground) background measurement. No source locations were fixed. With a

background measurement representative of the background response at the anomaly location, this second approach can work well. Unfortunately, for the Waikoloa dataset, the spatial variation in background response is large and the spatial coverage of the background measurements is poor (particularly for areas TO17 and TO20A). As a result, frequently either too much or not enough background is subtracted, leading to poor, unreliable inversion results.

Our belief was that this two-pronged approach, which results in a total of twelve models per anomaly, would provide the best chance of obtaining at least one good, representative model per anomaly.

Our stage 1 dig list comprised two parts. For part 1 (digs 1—214) classification was based on polarizability matching against a reference library using all three polarizabilities and the first 40 time channels (up to 6.41 ms). For part 2 (digs 215—939), classification was based on the data misfit with a soil model that we developed from Waikoloa MetalMapper soundings that look like pure soil response. For the latter, anomalies with data closely resembling the soil model appear later on the dig list. The soil model misfit is calculated using an arbitrary scale factor for each anomaly to account for amplitude variations associated with the varying strength of the magnetic soil response across the site. The transition point between the two parts of the dig list was chosen by visual inspection of the polarizabilities in dig list order, with the transition point positioned just ahead of the point where polarizabilities sorted by matching against the reference library returned a majority of soil anomalies. Anomalies near the front of the second part of the dig list should represent anomalies with a substantial presence of metal in the ground, though their match to items in the reference library will not necessarily be good. This was considered to be a conservative approach for ensuring non-soil anomalies occur ahead of soil anomalies.

Of the nine QC seeds we missed, only two (WK-402 and WK-715) were missed because their polarizability misfit was too large relative to the decision point we chose. For the other seven missed QC seeds, the data and polarizabilities are consistent with what we consider to be a typical soil response. For one of these seven (WK-73; 37mm TP at 11 cm depth; Figure 1), the offset between ground truth location and MetalMapper acquisition location is large (74 cm). This likely explains the soil response at this anomaly.

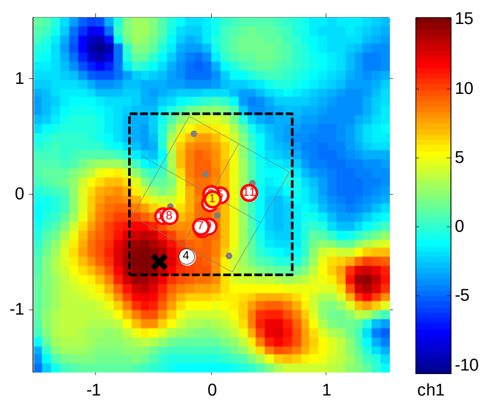


Figure 1. EM-61 data in the vicinity of WK-73 (37mm TP at 11 cm depth). Thin lines show outline of the MetalMapper. Broken black lines are horizontal inversion boundary. Circles are predicted model locations. Black “X” is ground truth location of the seed. Offset to center of the MetalMapper is about 74 cm.

b. Description of how the analysis procedures have been modified based on the additional information provided

QC seeds are typically missed because either (1) the polarizability match to reference items is somewhat worse than expected based on an assessment of overall data quality; or (2) the seed is a “one-off” item not discovered during training, and therefore not represented in the polarizability reference item. The corrective measure to take in both cases is obvious: either (1) modify the decision point so that items with larger polarizability misfits appear before the stop dig point; or (2) add the new item to the polarizability reference library. For this dataset, however, the key issue with most of the missed QC seeds is that the data contain no obvious signal beyond a soil response, resulting in recovered polarizabilities that bear no resemblance to those of the associated library item(s). This is exemplified by anomaly WK-707 (37mm ATP at 20 cm depth;

Figure **2** and **Figure 3**). The similarity between the observed data and the soil model resulted in this anomaly appearing at dig number 568. There was no possibility that this anomaly would be dug early. A similar situation exists with WK-203, 391, 393, 474 and 1026 (See Appendix for data and polarizabilities of these anomalies). Figure 4 shows polarizabilities for digs 541-576 and illustrates the difficulty in recognizing two of the missed QC seeds (WK-393 and WK-707) whose polarizabilities look very much like those from other soil anomalies. For this site, with several QC seeds that cannot be detected due to a very strong soil response, and given the assumption that the objective at this site is to find *all* TOI, and assuming that the ground truth information is reliable, the prudent approach is to *dig all anomalies*.

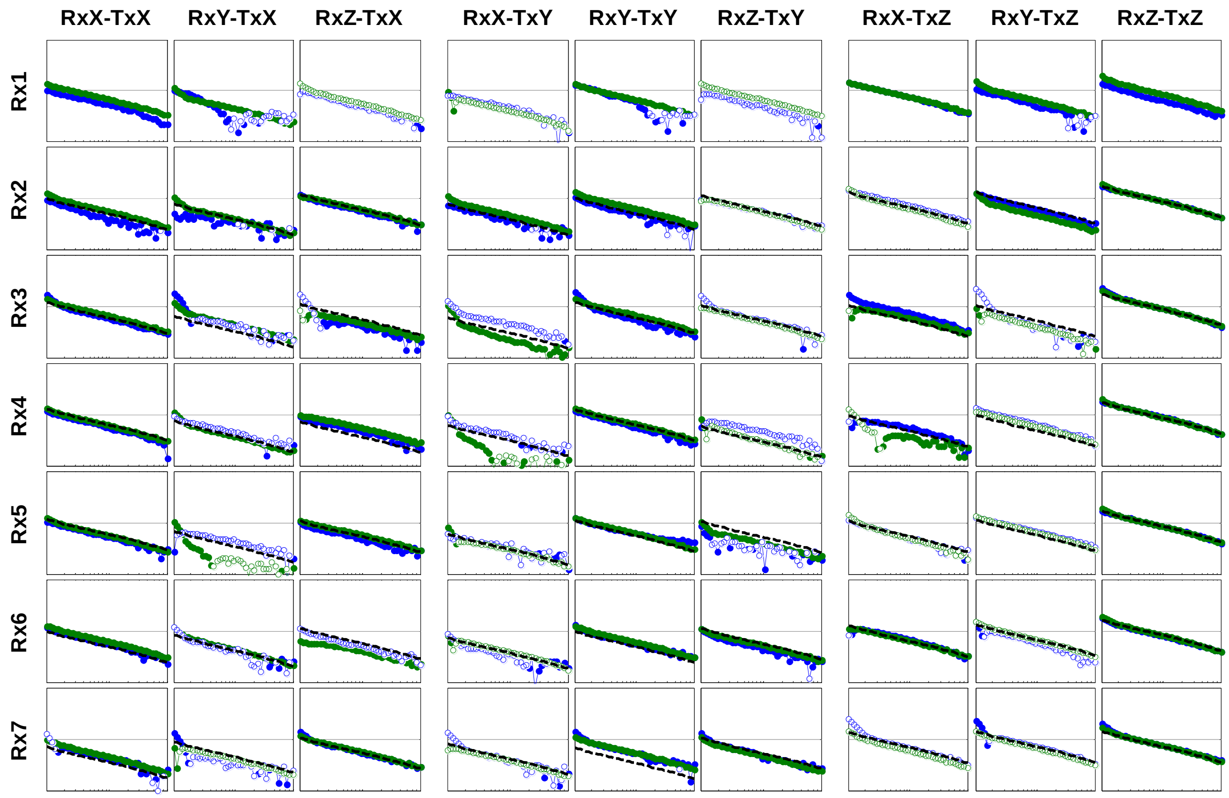


Figure 2. Data for missed QC seed WK-707 (37mm APT at 20 cm depth). Blue: observed data. Green: predicted data. Broken black line: soil model. In general all soundings are an excellent match to the soil model (so that the observed and predicted data are obscured by the black line). Receiver 1 (top row) data were generally bad for all anomalies and were not included in the inversions.

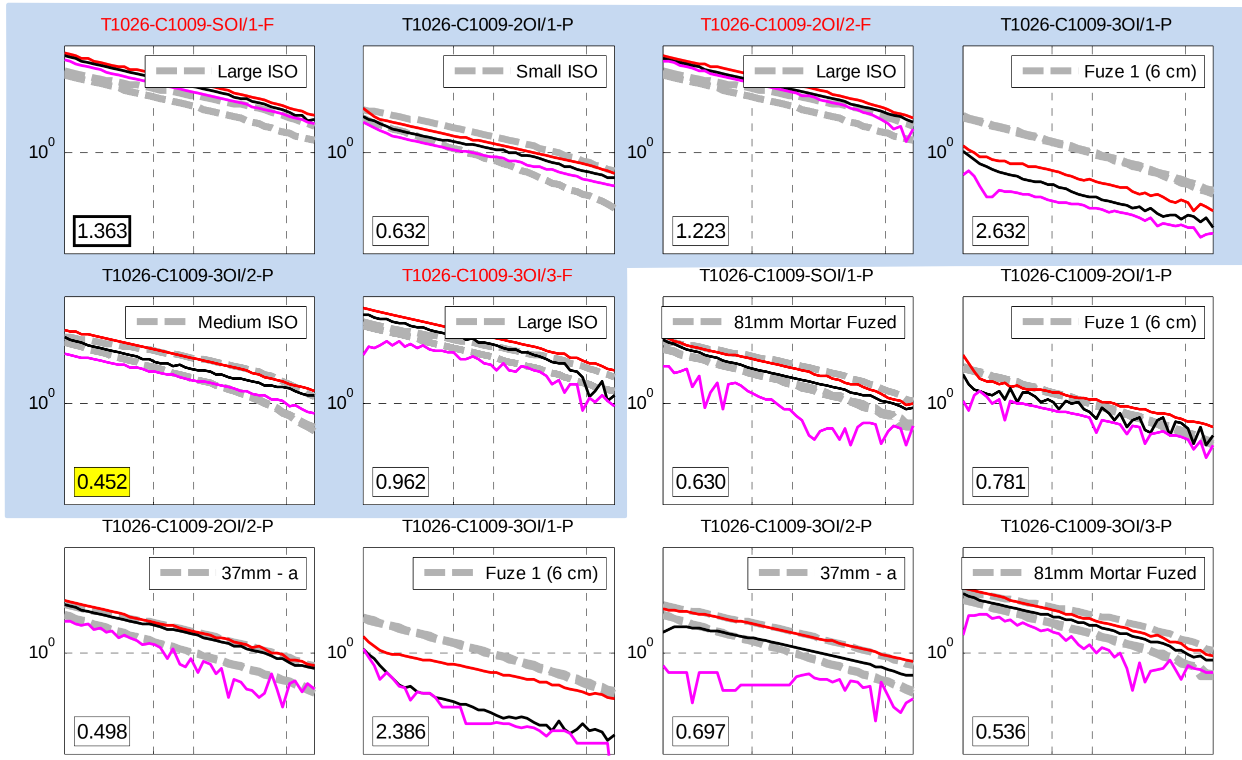


Figure 3. Polarizabilities for missed QC seed WK-707 (37mm APT at 20 cm depth). The first six models (light blue background) used data background corrected using the nearest in-air measurement and, for the two-object (2OI) and three-object (3OI) inversions, fixing one of the sources at 90 cm depth. The remaining six models used data that were corrected using the nearest near-ground background correction. Red, black and magenta lines are predicted polarizabilities. Broken grey lines are best fitting reference library polarizabilities. The predicted polarizabilities for all models are typical of a soil response. None of the models remotely resemble any of the 37mm reference items.

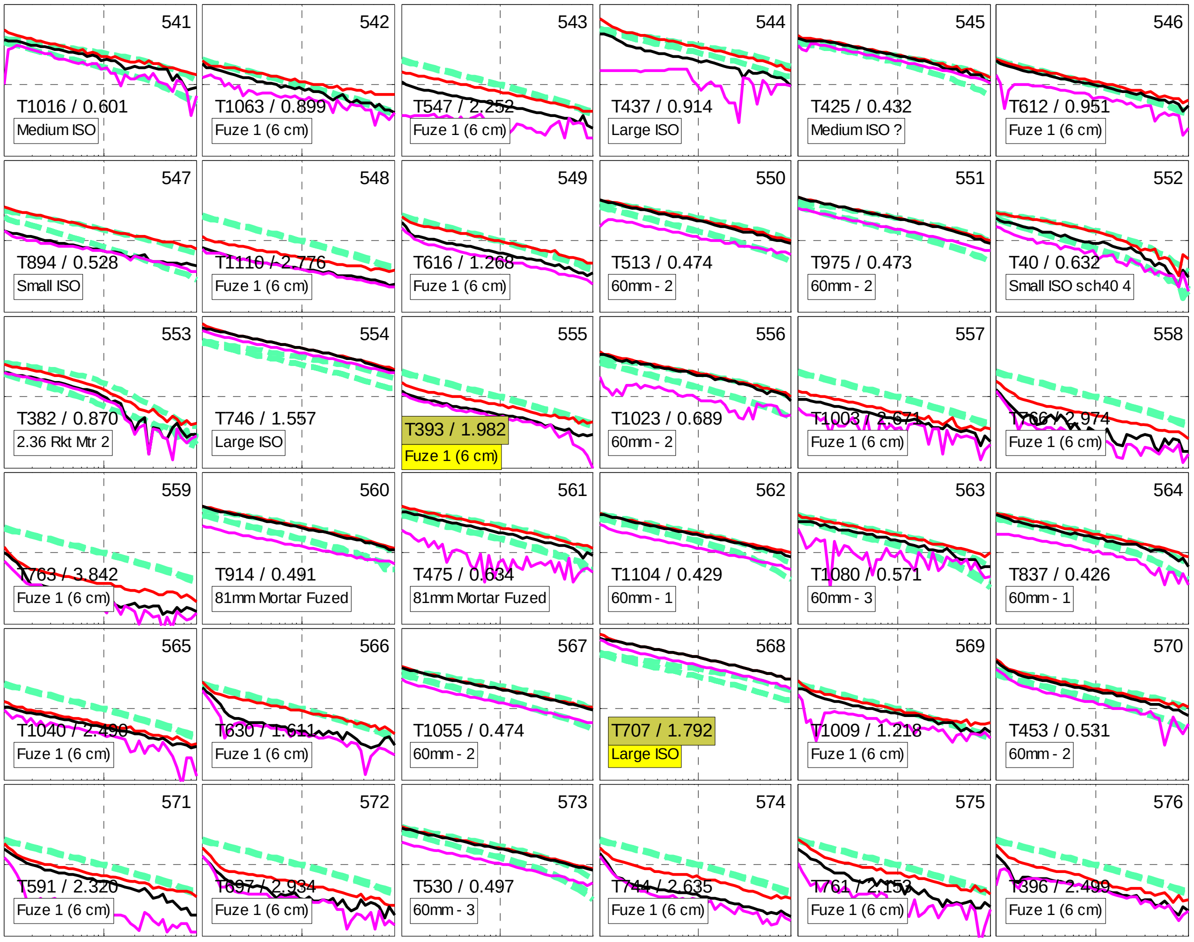
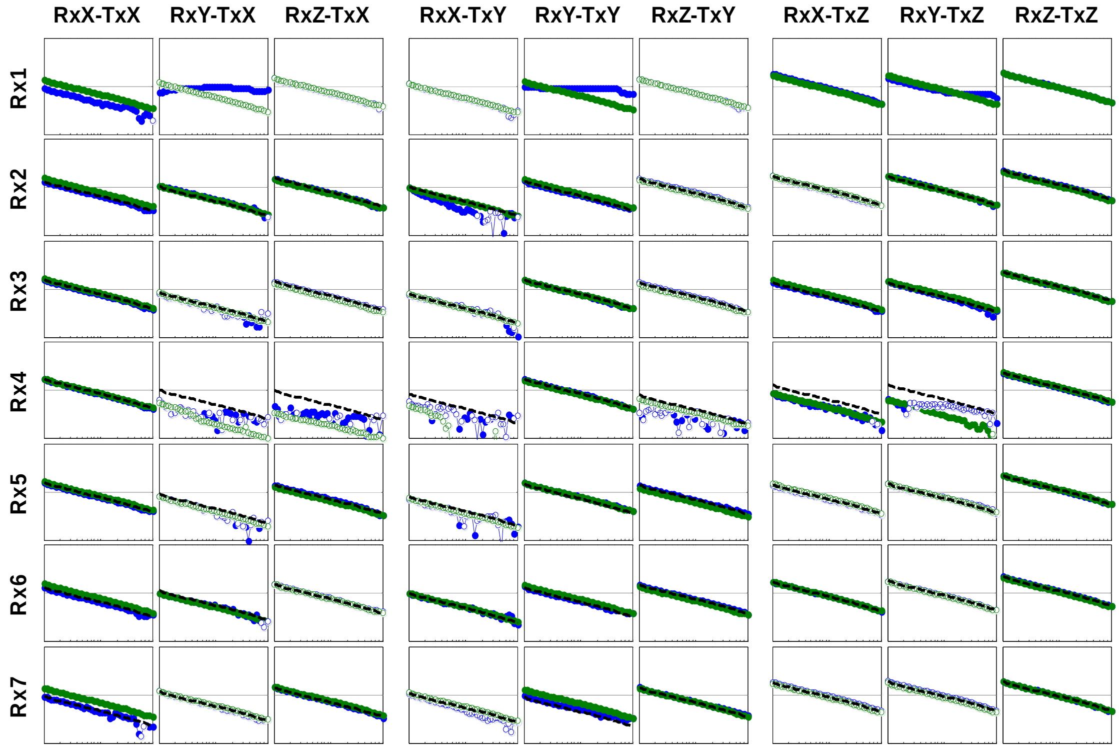


Figure 4. Polarizabilities in dig list order for digs number 541 through 576. Missed QC seeds are indicated by colored labels: WK-393 (60mm mortar; dig 555) and WK-707 (37mm; dig 568). All of the anomalies shown here have data which closely match our soil model.

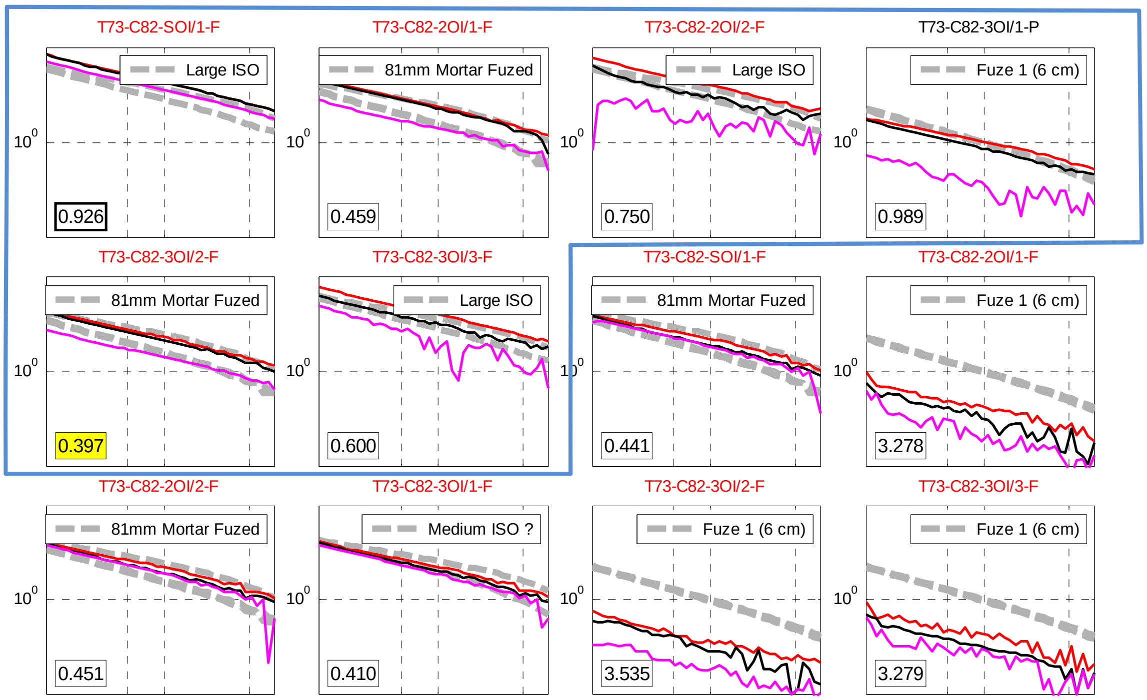
c. Evidence that the modified analysis scheme correctly classifies the missed seeds and can reasonably be expected to correctly classify all remaining TOI.

Digging all anomalies will correctly classify the missed seeds and will correctly classify all remaining TOI.

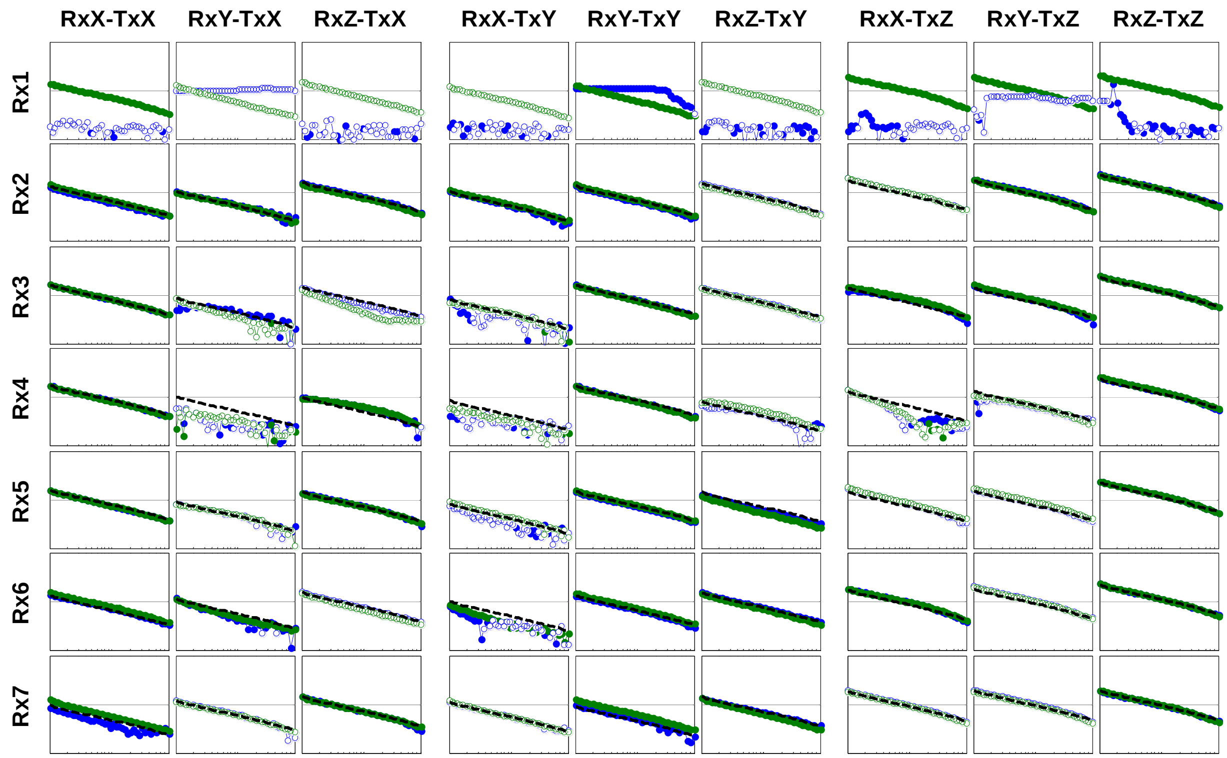
Appendix: Data and polarizabilities for other soil-like missed QC seeds



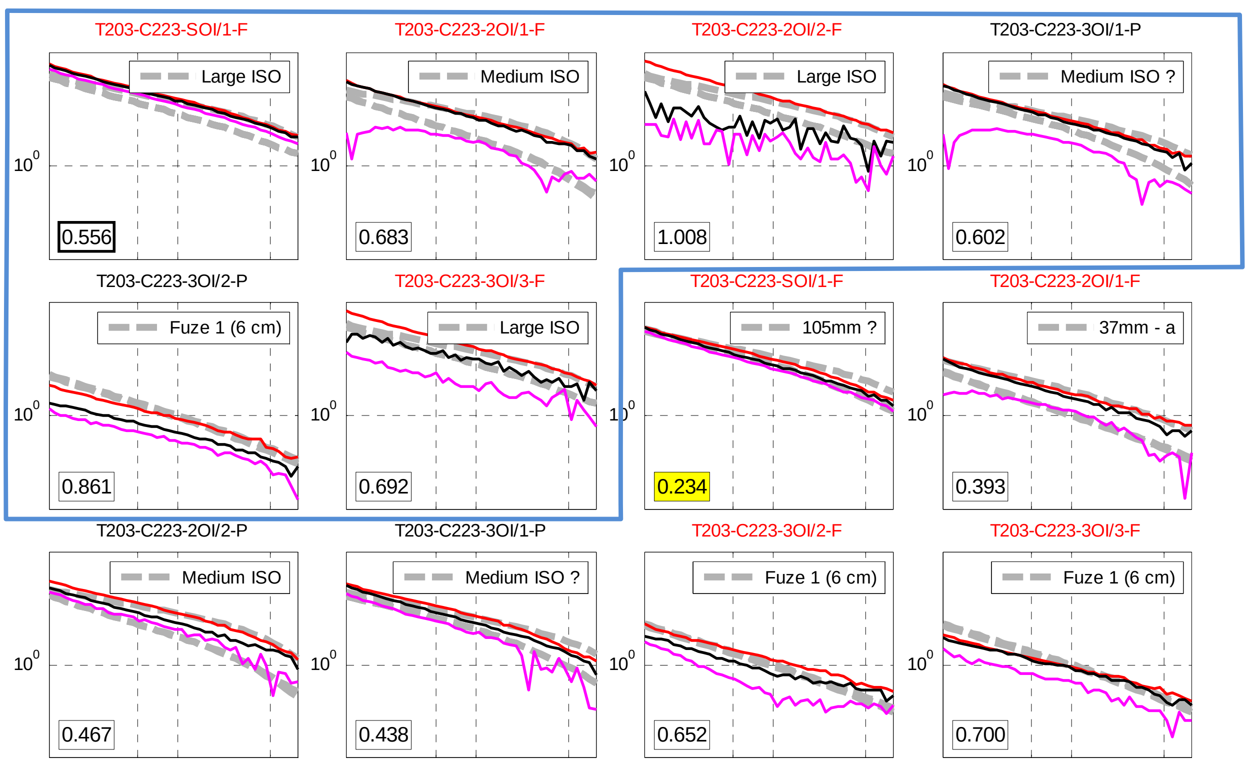
Data for missed QC seed WK-73: 37mm TP at 11 cm depth.



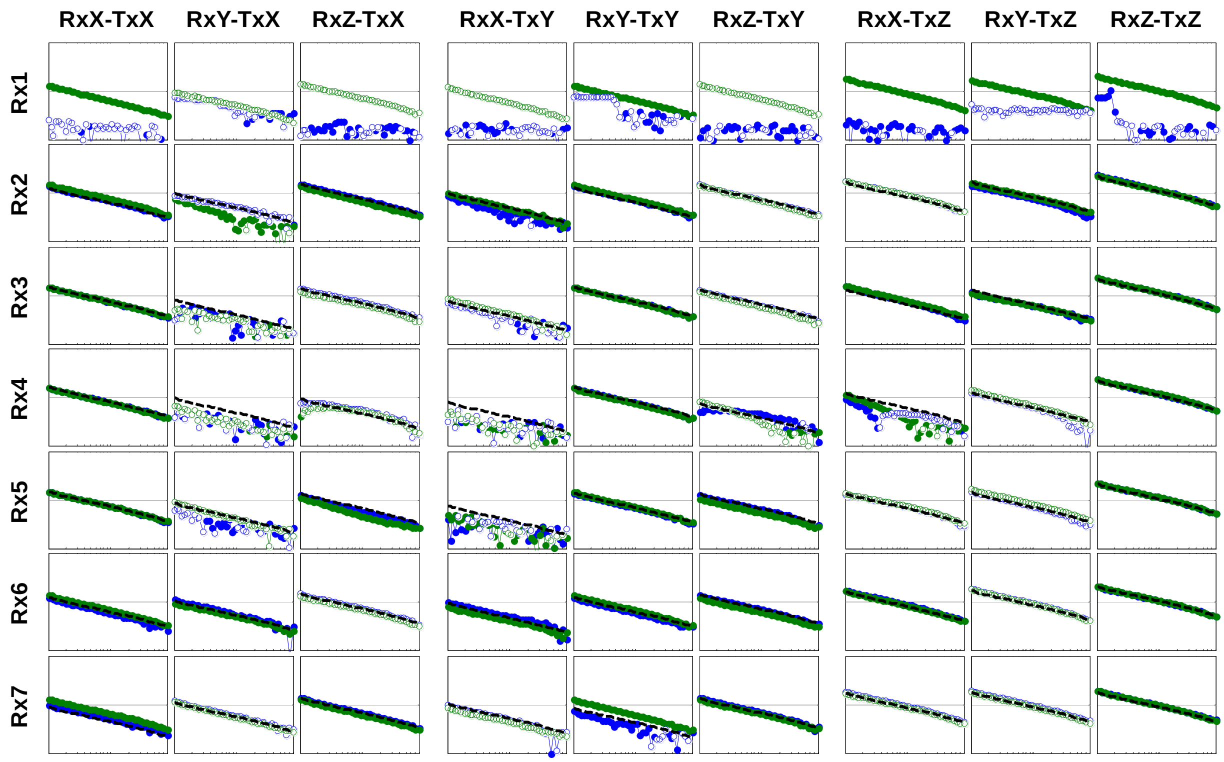
Polarizabilities for missed QC seed WK-73: 37mm TP at 11 cm depth.



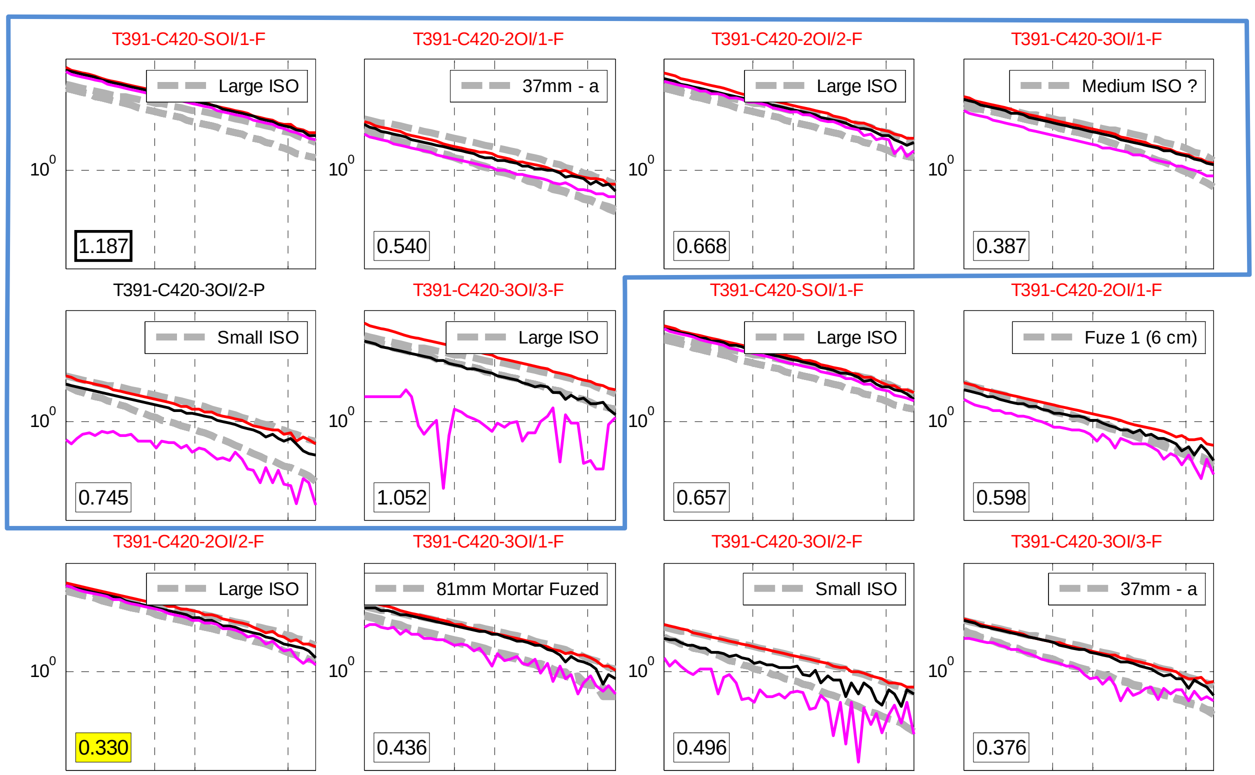
Data for missed QC seed WK-203: 60mm at 40 cm depth.



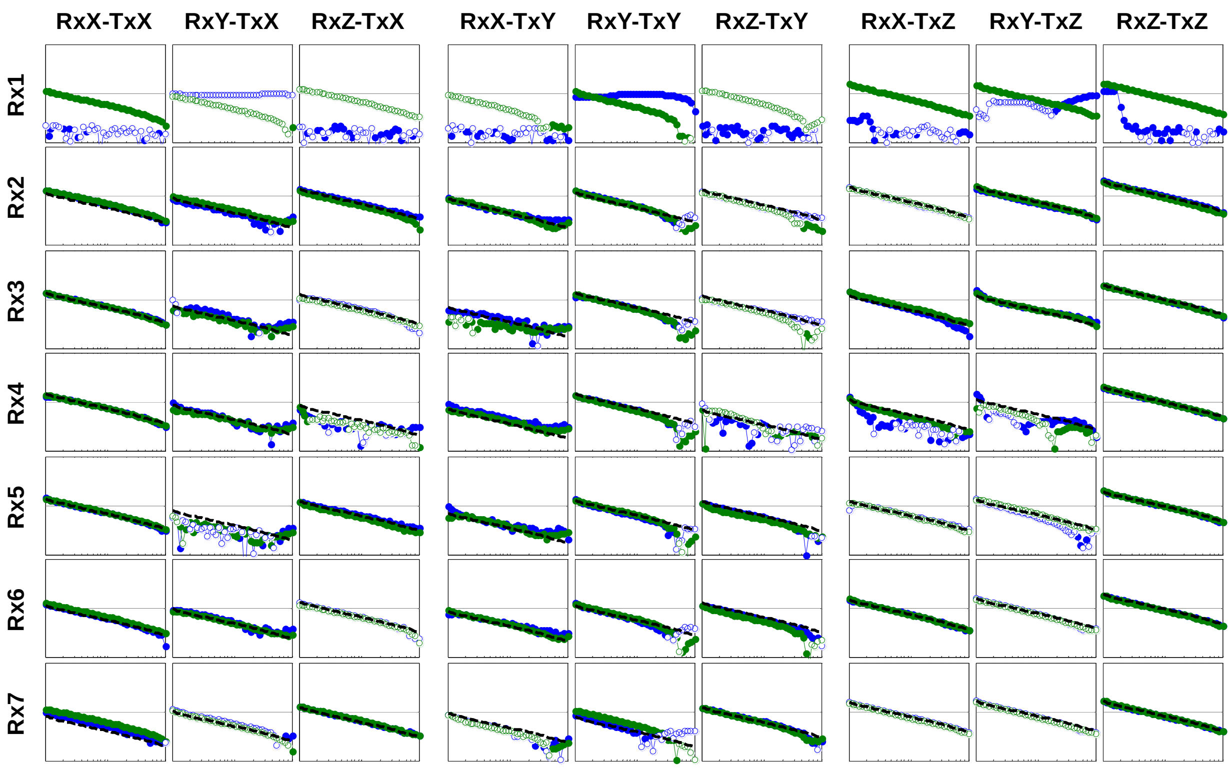
Polarizabilities for missed QC seed WK-203: 60mm at 40 cm depth.



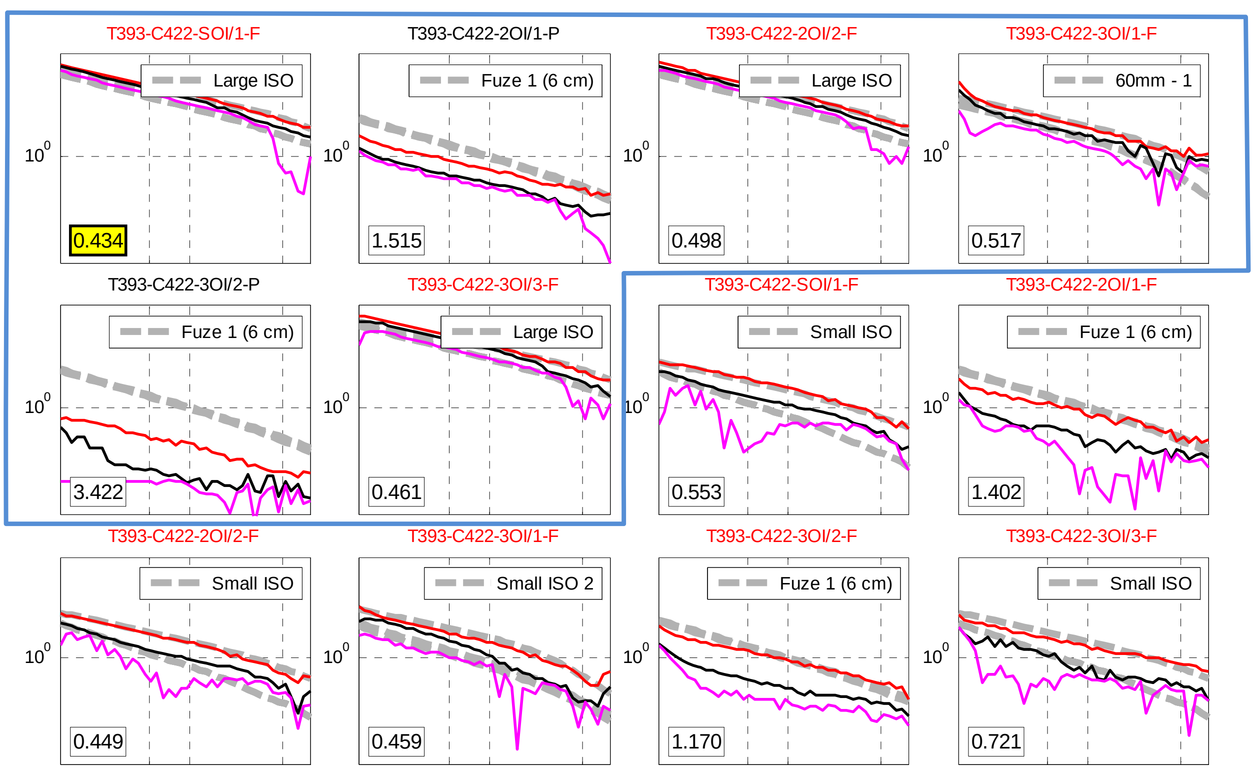
Data for missed QC seed WK-391: 60mm at 45 cm depth.



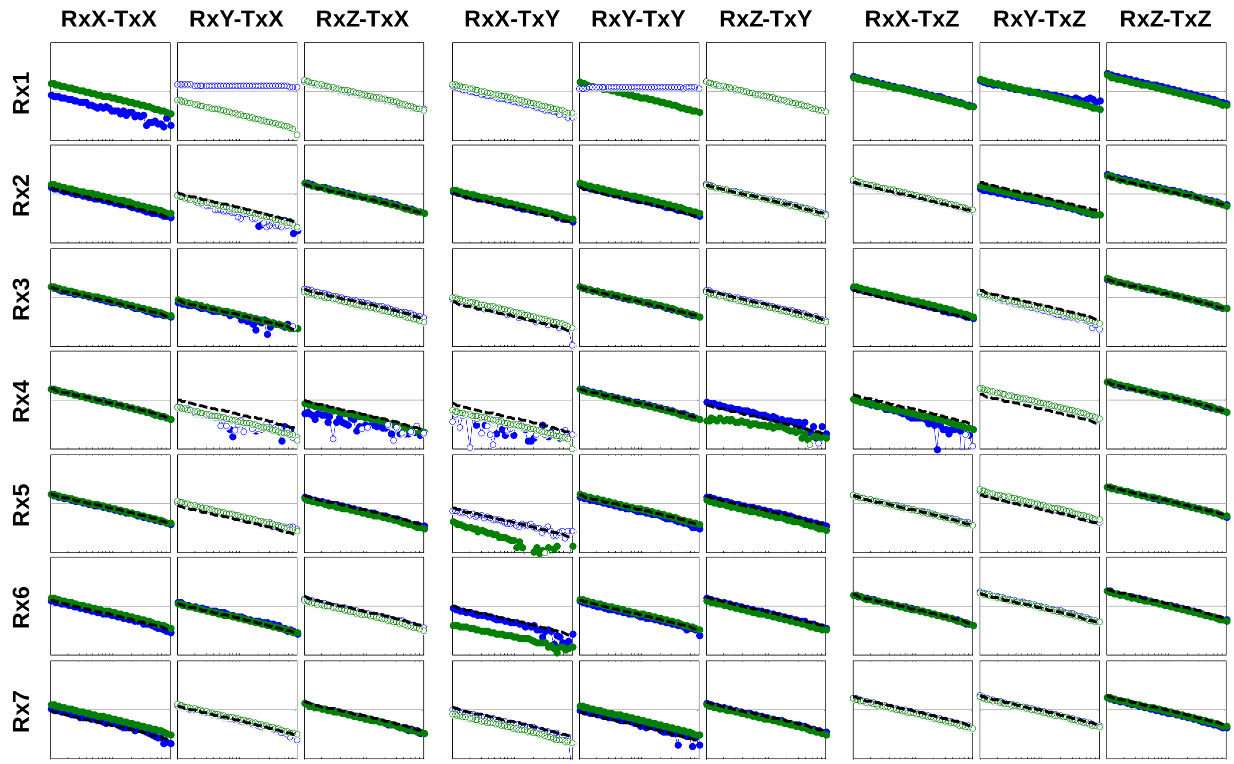
Polarizabilities for missed QC seed WK-391: 60mm at 45 cm depth.



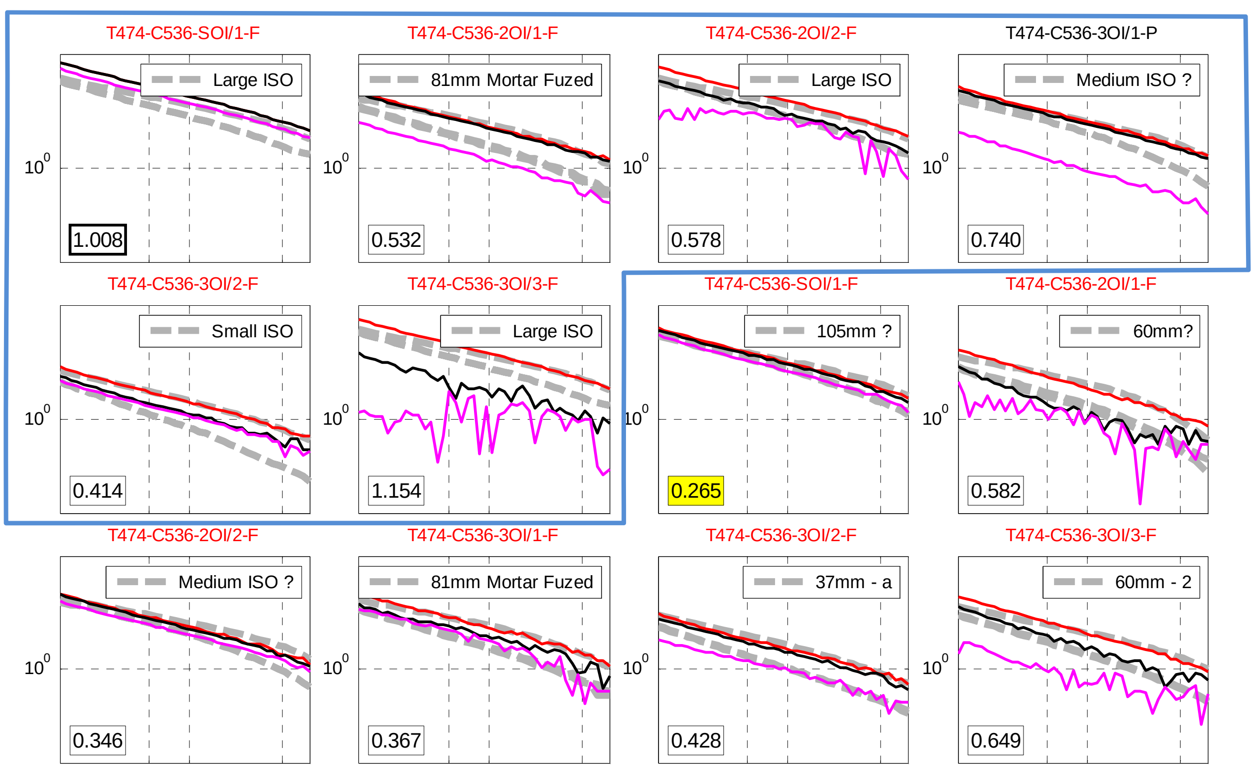
Data for missed QC seed WK-393: 60mm at 45 cm depth.



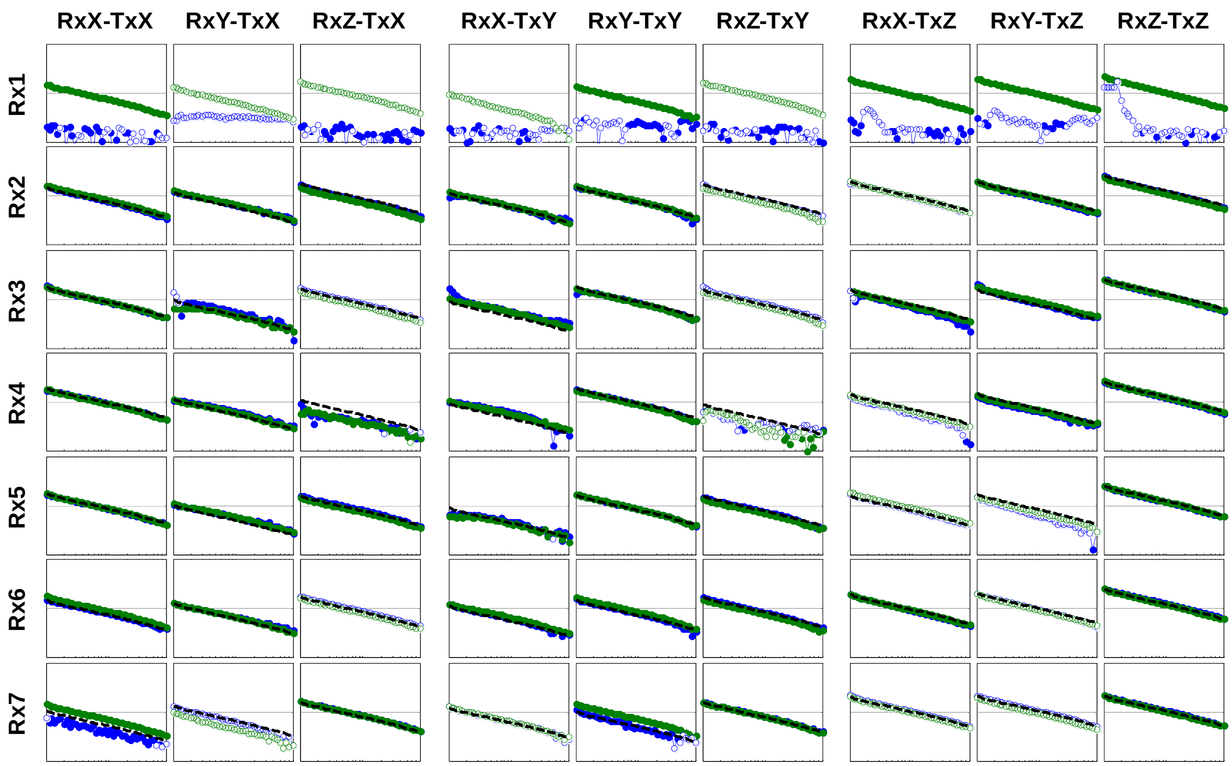
Polarizabilities for missed QC seed WK-393: 60mm at 45 cm depth.



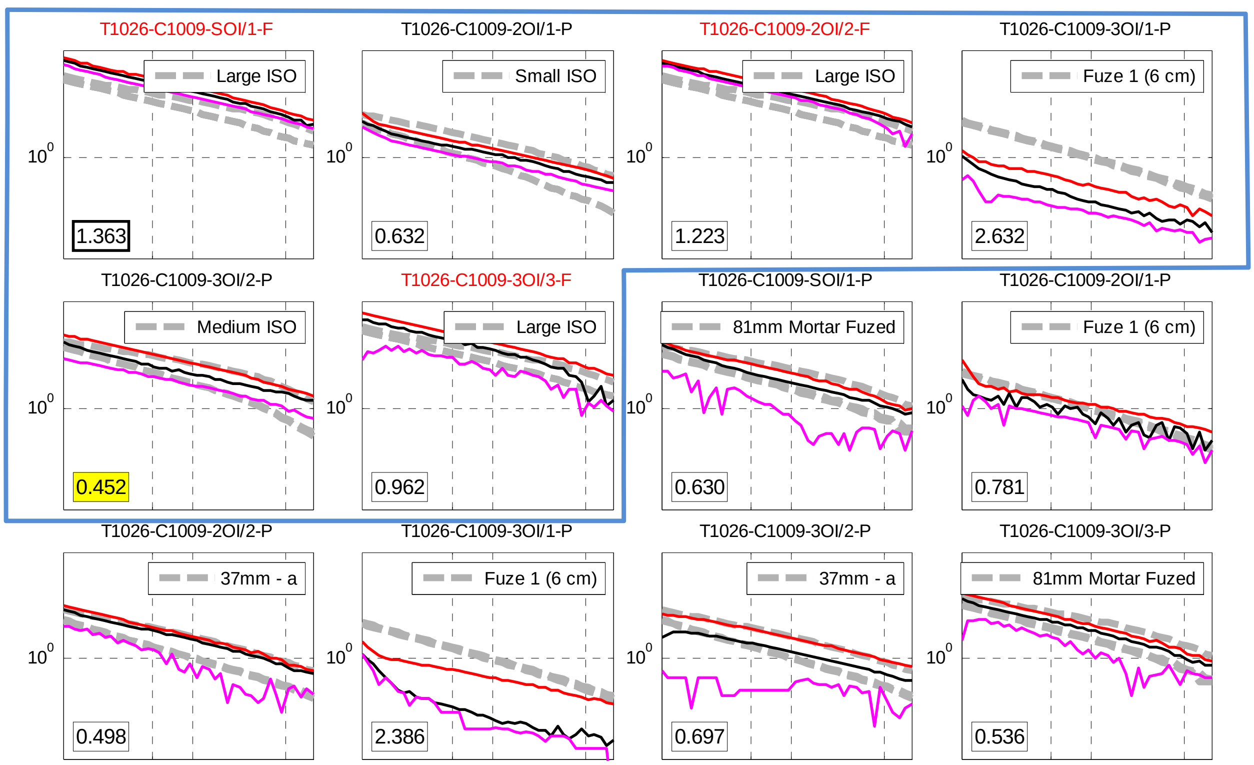
Data for missed QC seed WK-474: 60mm at 40 cm depth.



Polarizabilities for missed QC seed WK-474: 60mm at 40 cm depth.



Data for missed QC seed WK-1026: 60mm at 34 cm depth.



Polarizabilities for missed QC seed WK-1026: 60mm at 34 cm depth.